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AFSWP Report #717

UNITED STATES NAVY

REPORT ON PHASE II
of the
PRESSURE-HEIGHT PREDICTION PROJECT

VOLUME III

PROJECT
A-R-O-W-A

Bureau of Aeronautics Project Arowa (TED-UNL-MA-501)
"Applied Research; Operational Weather Analyses"
(AROWA)

U. S. Naval Air Station
Building R-48
Norfolk, Virginia

April 1954

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BUREAU OF AERONAUTICS PROJECT AROWA (TED-UNL-MA-501)
"Applied Research; Operational Weather Analyses"

Report on Phase II

of the

Pressure-Height Prediction Project

Volume III

BUREAU OF AERONAUTICS PROJECT AROWA
BUILDING R-48
U.S. NAVAL AIR STATION
NORFOLK 11, VIRGINIA

April 1954

ABSTRACT

By applying the technique outlined in Volume II, the mean 500-mb contour pattern is projected through a silent area. A few examples of this process are included.

A new framework for pressure-height forecasting is established and the present stage in implementing this procedure indicated. It is emphasized that research now in progress will reveal ways of improving such forecasts.

Estimates of the errors inherent in various methods of predicting pressure height are given. In the concluding chapter some interesting problems that arose in the course of research are discussed.

CONTENTS OF VOLUME III

INTRODUCTION

The research devoted to Phase II of the Pressure-Height Prediction Project is summarized in Volume I of this report. An attempt is made in Volume II to outline and illustrate some of the meteorological procedures and analyses required for the preparation of pressure-height forecasts. The problem has been considered on a hemispheric scale with attention directed at a mid-tropospheric level from which upward and downward extrapolations are possible. In this present volume a list of preliminary rules for extending mean contour patterns through areas of the globe devoid of meteorological data are listed and illustrated by example. The present concept of the forecasting problem is discussed together with some remarks about future avenues of attack, and estimates of the accuracy of both pressure-height and wind forecasts are discussed.

CHAPTER I. APPLICATION OF 500-MB CONTOUR PATTERNS TO EXTENDING MEAN CONTOUR PATTERNS THRU SILENT AREAS.

1. Basic Rules

The study of mean charts (mostly 5-day means, with a few 20° diamond space-means) has made clear the behavior of hemispheric patterns of flow. The rules given below are meant as guides in extrapolating the mean pattern through a "silent area" (i.e., an area from which weather reports are not to be expected). This extrapolation represents the first step in preparing a pressure-height forecast.

(1) The trough over the East Coast of Asia is the most permanent feature of the mean flow and may be regarded with confidence as an anchor trough for prognosticating a pattern.

(2) In a first approximation, a stable block is symmetrical about a north-south line through its center.

(3) Near zonal flow with broad, flat troughs is common upstream and downstream from a block.

(4) A weak block (i.e., with a departure from normal of less than 1000 feet) may be considered a combination of a long-wave ridge and two long-wave troughs. More intense blocks should not be thought of in terms of long waves.

(5) When a strong block is present near 0° longitude, the first

(14) When a block lies over the Pacific and when the flow is zonal over the Atlantic, there will be a block over Eurasia.

(15) Space-averaged mean contours approximate Constant Absolute Vorticity trajectories.

These rules were followed in the examples provided.

2. Examples

The forecaster was supplied with a chart on which selected contours had been drawn. The Eurasian area was considered "silent" and the mean contours were to be extended through it.

The actual five-day mean chart used is included below for purposes of verification. (The space-averaged mean chart gives a smoother representation and thus makes extension easier.)

The contours furnished to extrapolate the flow were for 18, 400 feet and 17, 200 feet (shown as solid heavy lines) and for 18, 800; 18, 000; 17, 600; and 16, 800 feet (shown as solid light lines). Broken contours represent extensions.

The rules applicable are listed for each case.

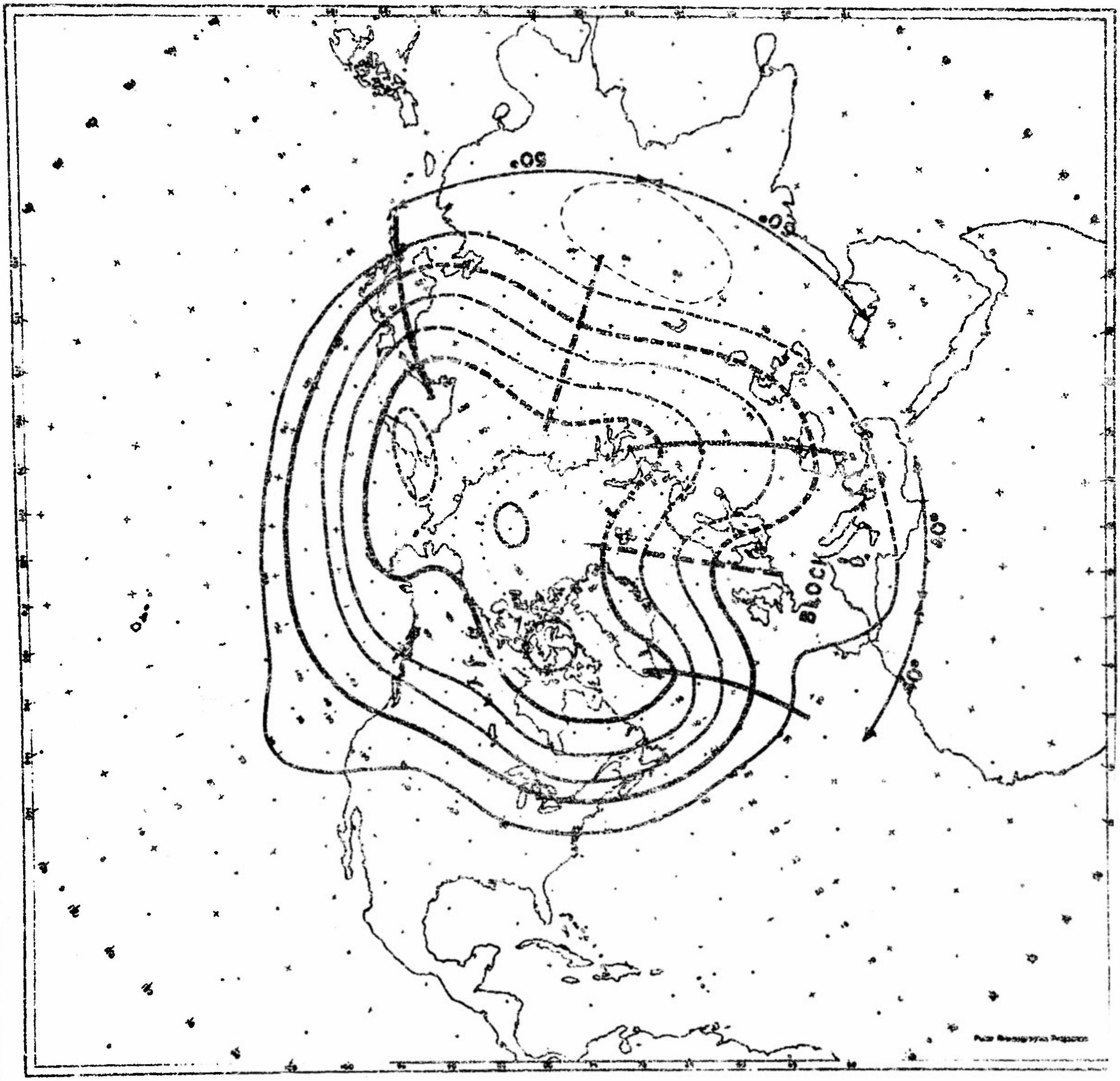
Example 1 : Figure 1

Symmetry with respect to the block at 5° E establishes the location and shape of the trough at 45° E. (Rule 2)

The known contours establish the East Asian trough at 140° E. (Rule 1)

Constant Absolute Vorticity trajectory places the intervening ridge at 95° E. (Rule 15)

Figure 1a. The actual contours verify this extension.



Example 1 - Figure 1. Extended Mean Contours For 23 October 1950

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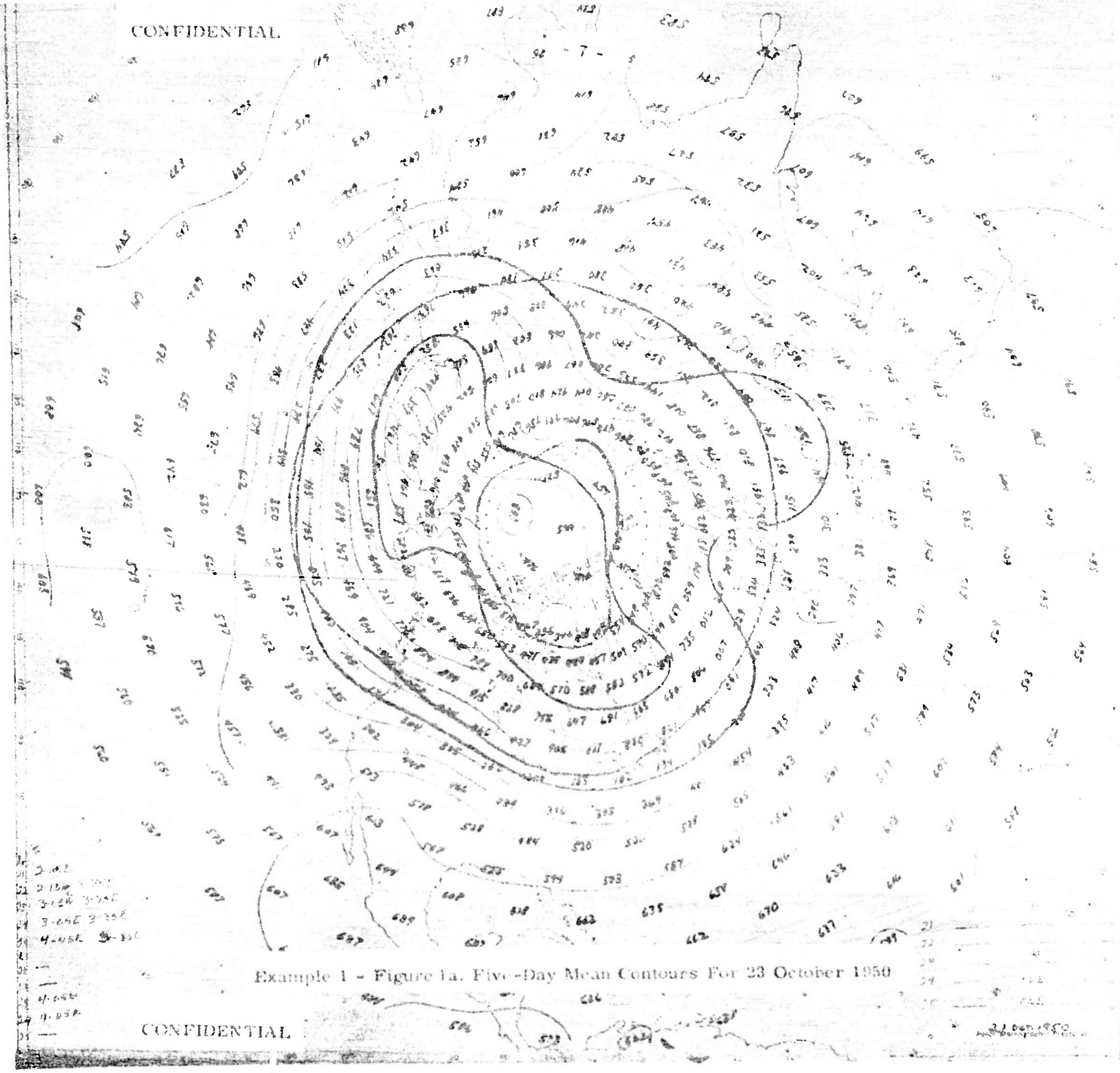

Example 1 - Figure 1a. Five-Day Mean Contours For 23 October 1950

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Example 2 : Figure 2

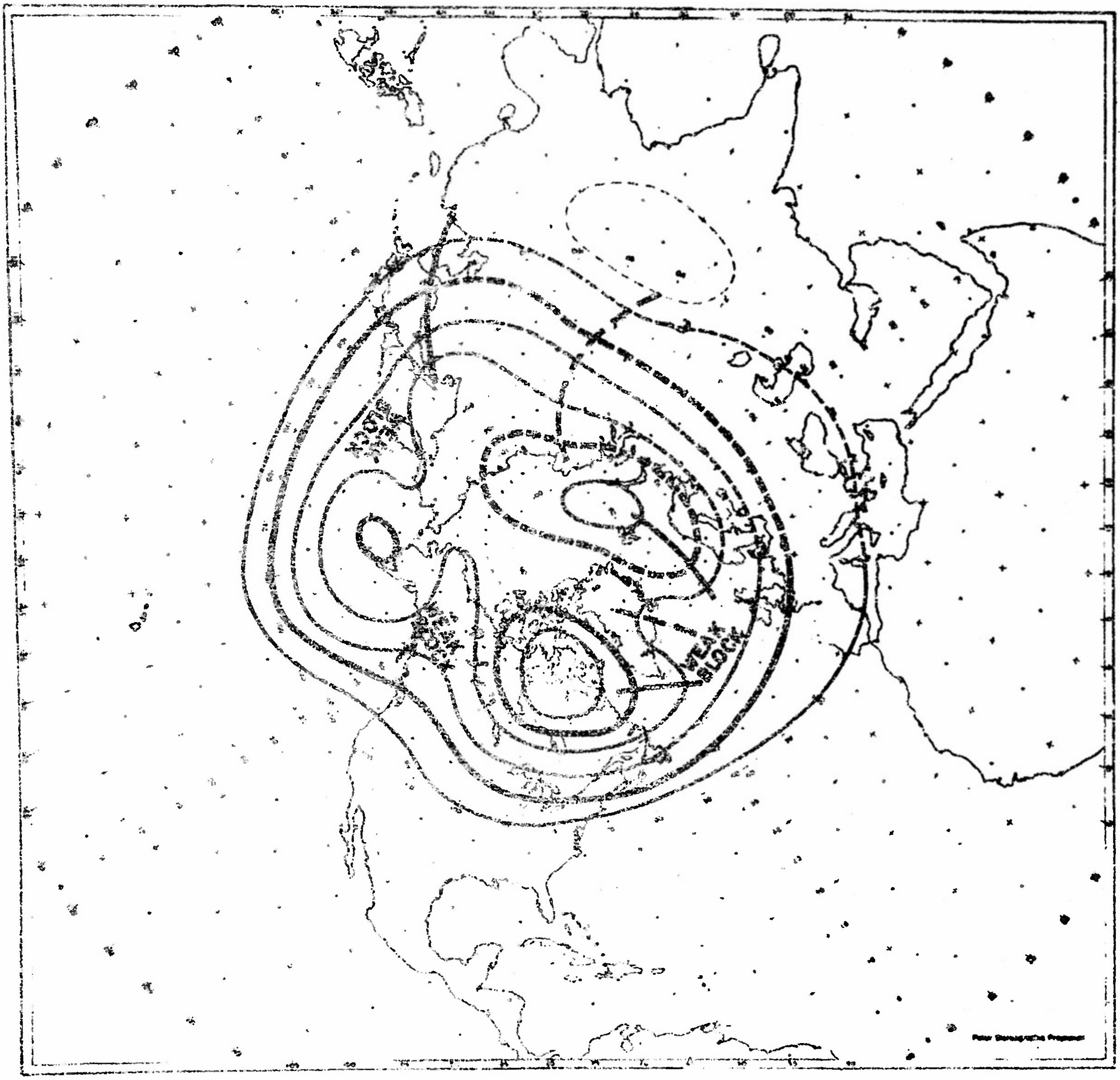
Symmetry with respect to the weak block at 25° W establishes the weak trough at 15° E. (Rule 2)

The presence of a weak block over the Kamchatkan Peninsula locates the East Asian trough somewhat west of its normal position.

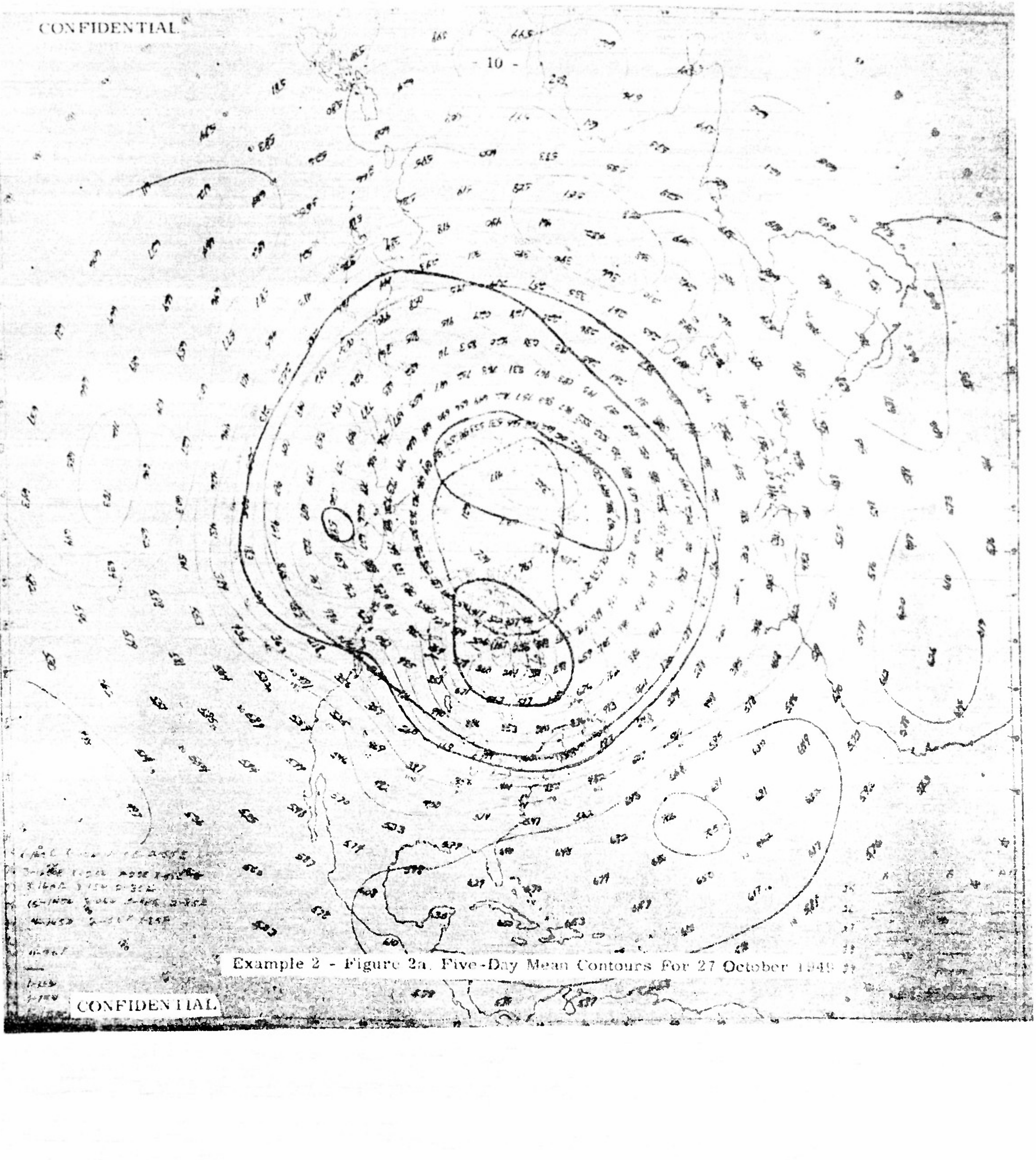
Because of these two blocks and another block over North Western Canada, the presence of a block over Eurasia is unlikely. (Rule 13 and the converse of Rule 14)

Since a near-zonal pattern has now been established, a weak ridge is placed at 90° E. (Rule 15 - Vorticity Symmetry)

Figure 2a: This verifies well, except for a missing trough and ridge over the Caspian Sea south of the main stream of westerlies.



Example 2 - Figure 2. Extended Mean Contours For 27 October 1949



Example 2 - Figure 2a. Five-Day Mean Contours For 27 October 1949

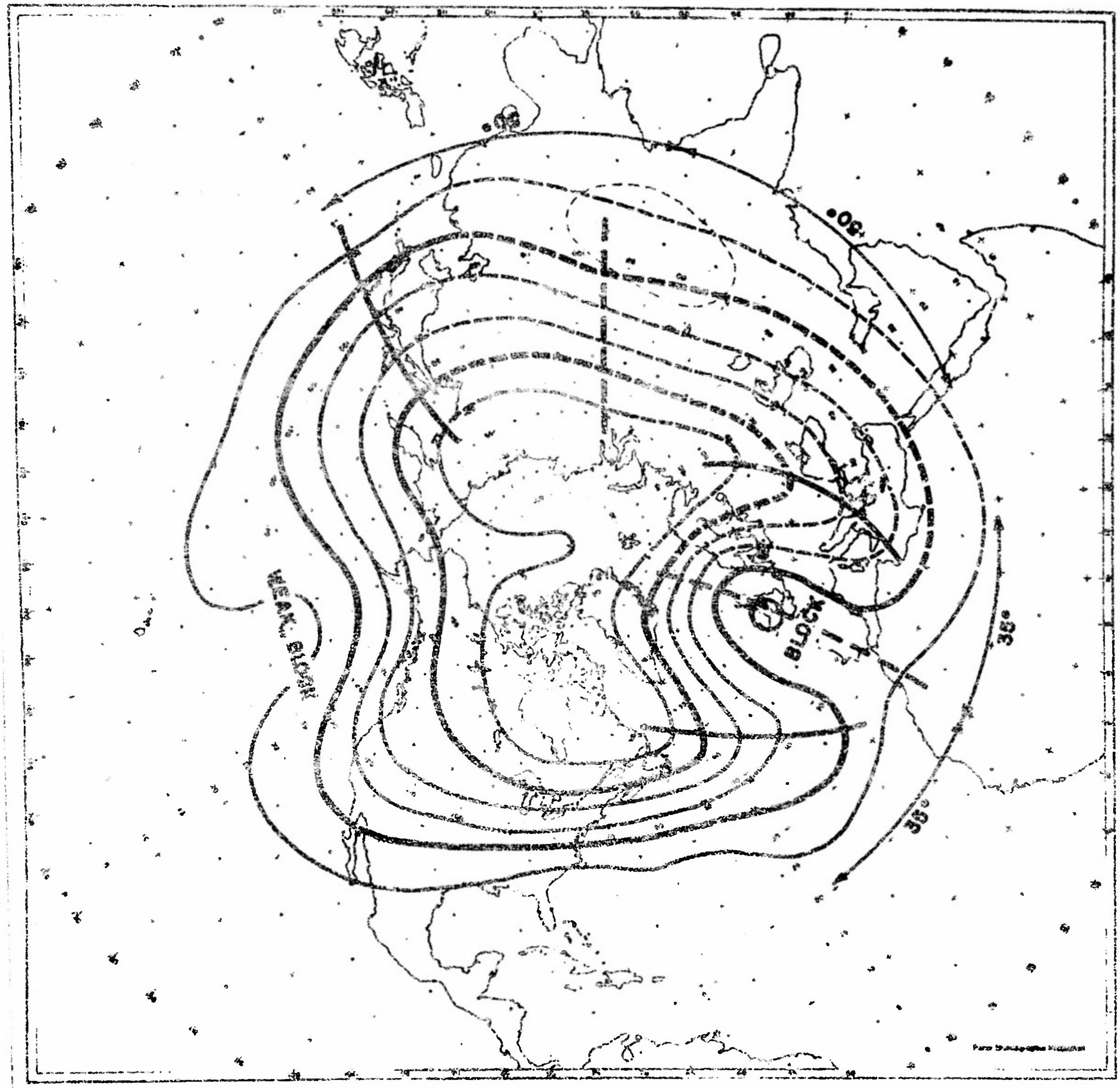
Example 3 : Figure 3

Symmetry with respect to the block at 10° W establishes the location, intensity, and tilt of the next trough over Eastern Europe. (Rule 2)

This block, together with the block over the Mid-Pacific, makes impossible the existence of a block over Asia. (Rule 5)

The weak ridge over Mid-Asia is located by halving the distance, measured trough to trough, between the European and Asian troughs.

Figure 3a. This pattern verifies well.



Example 3 - Figure 3. Extended Mean Contours For 3 February 1949

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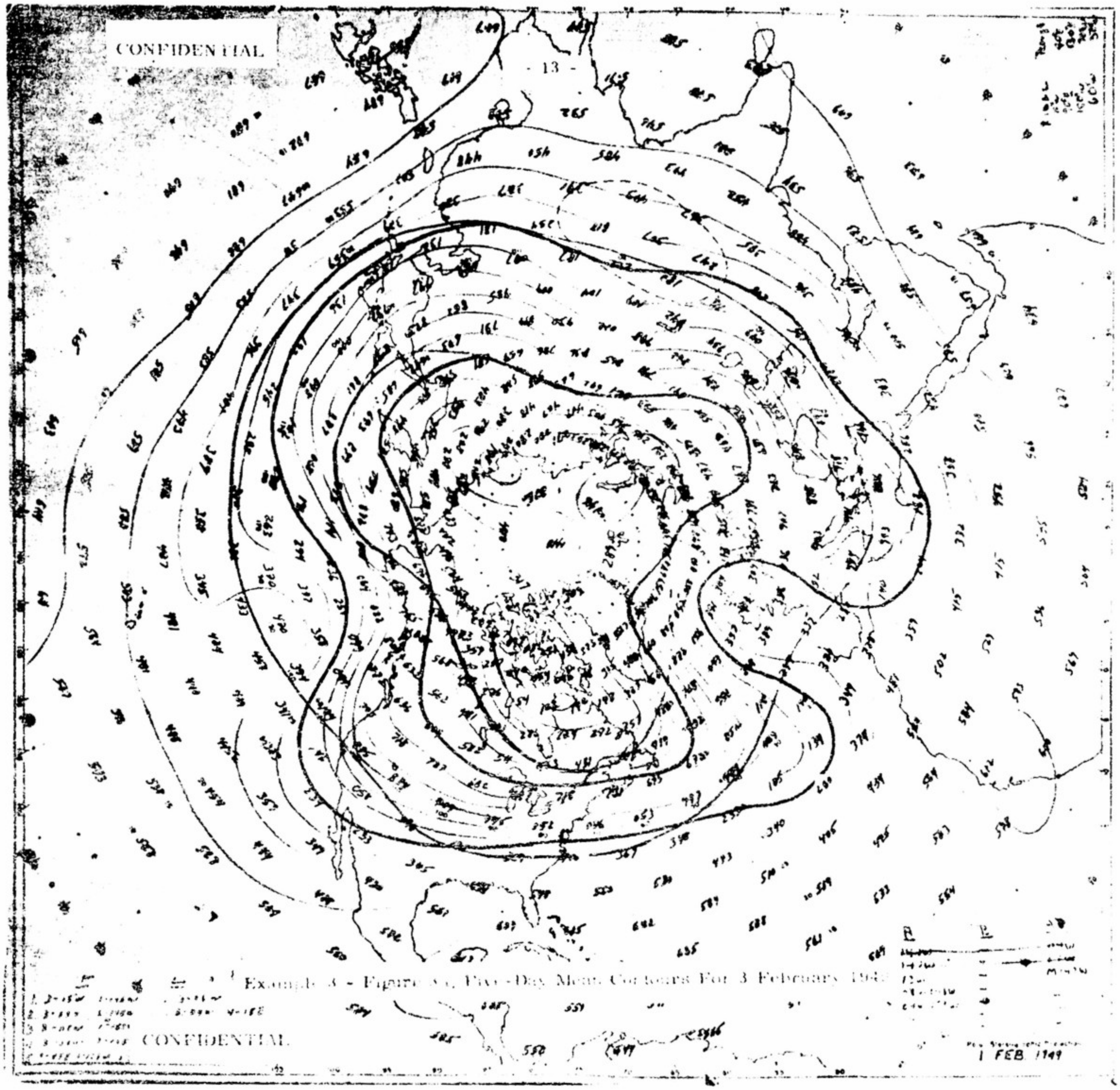

Example 3 - Figure [illegible], Five-Day Mean Contours For 3 February 194[illegible]

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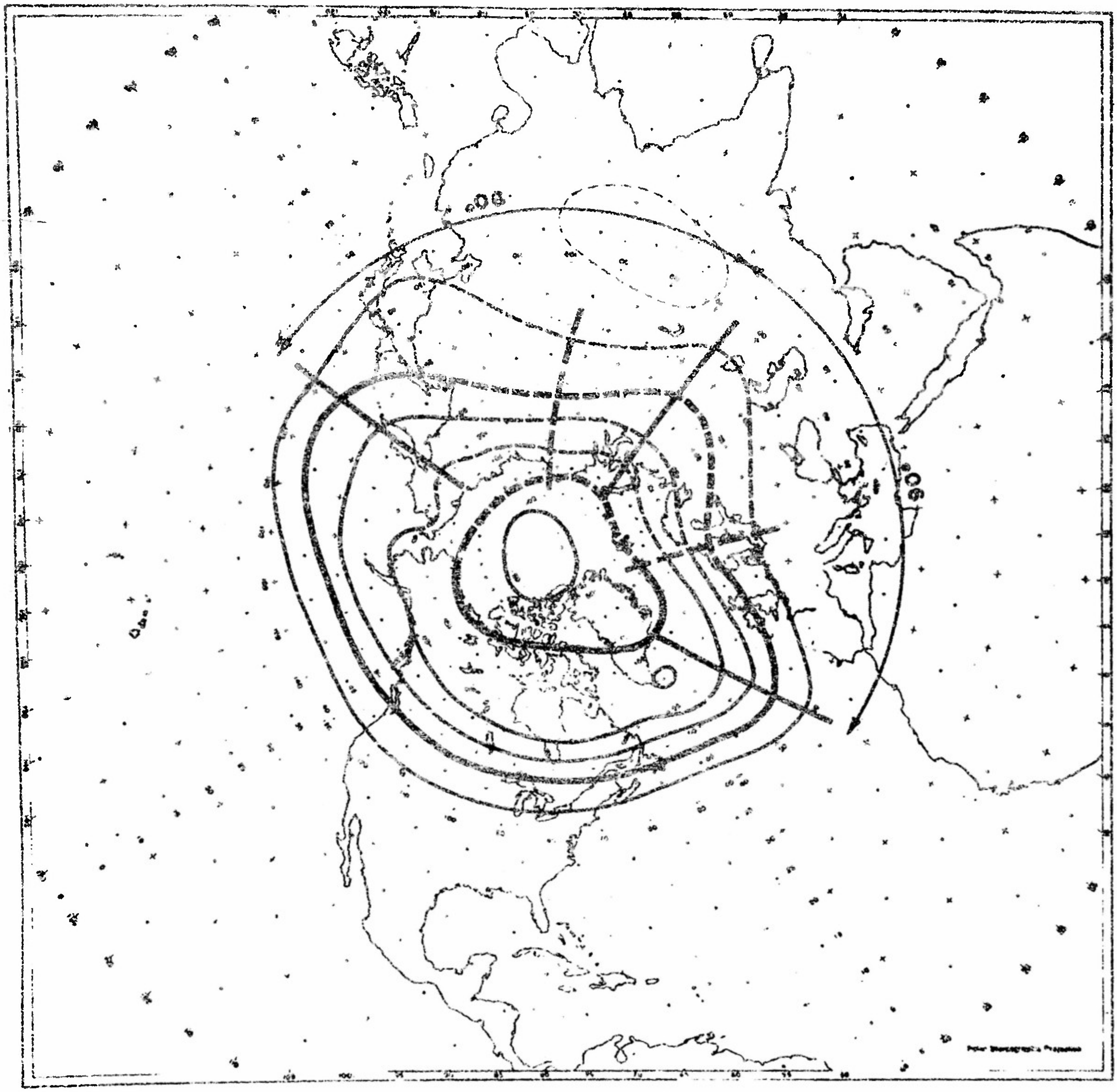
Example 4 : Figure 4

The absence of a block in the known area makes impossible the existence of a block over the silent area. (Rule 12)

At 55° N the trough over the Atlantic is located at longitude 25° W; at the same latitude the East Asian trough is at 155° E. The trough-to-trough distance between the two measures 180°, thus placing the Mid-Asian trough at 65° E. The absence of tilt in the Atlantic trough may indicate a north-south orientation of the Asian trough.

Figure 4a: The depth of the Asian trough was underestimated.



Example 4 - Figure 4. Extended Mean Contours For 15 October 1949

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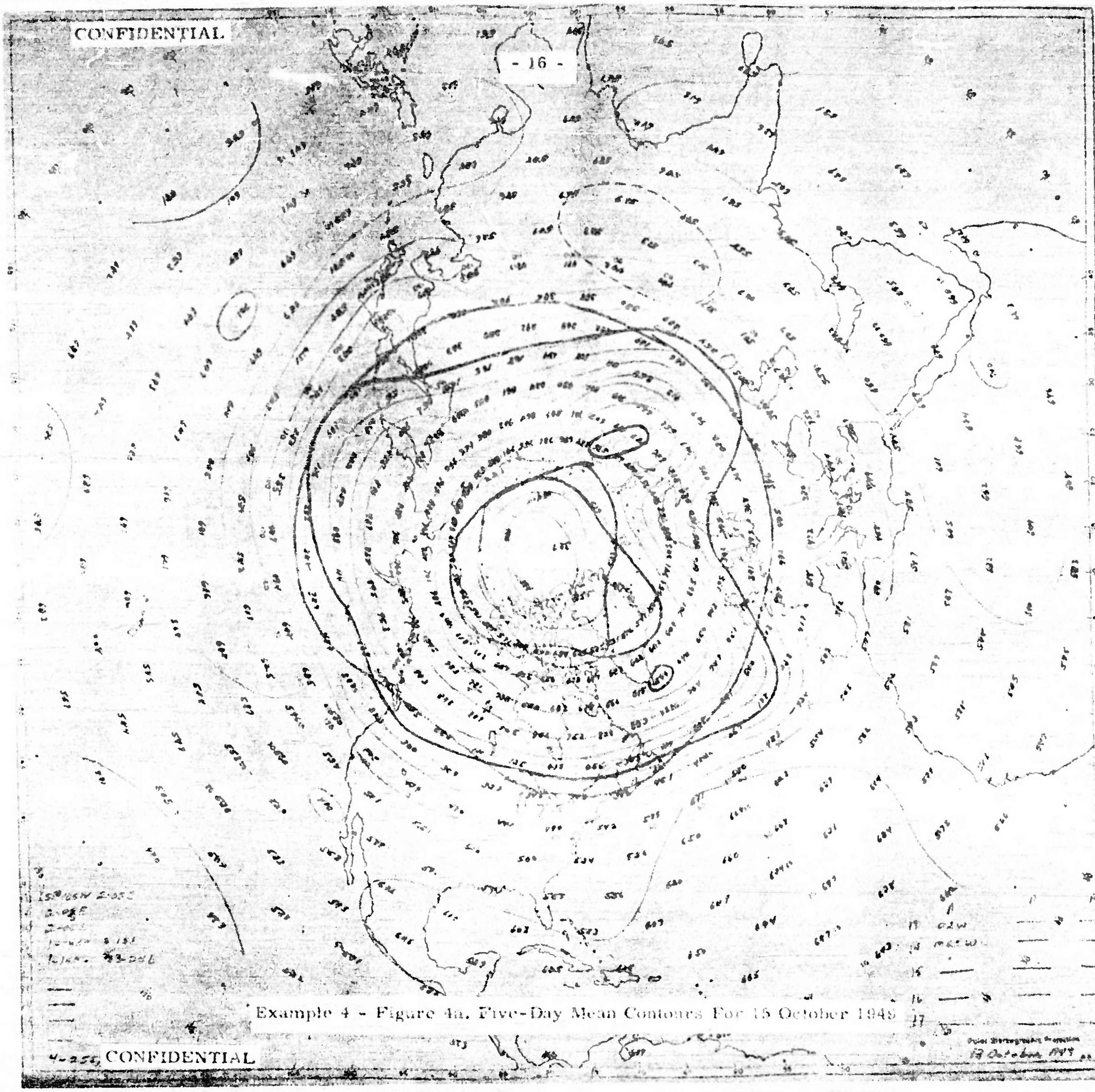

Example 4 - Figure 4a. Five-Day Mean Contours For 15 October 1949

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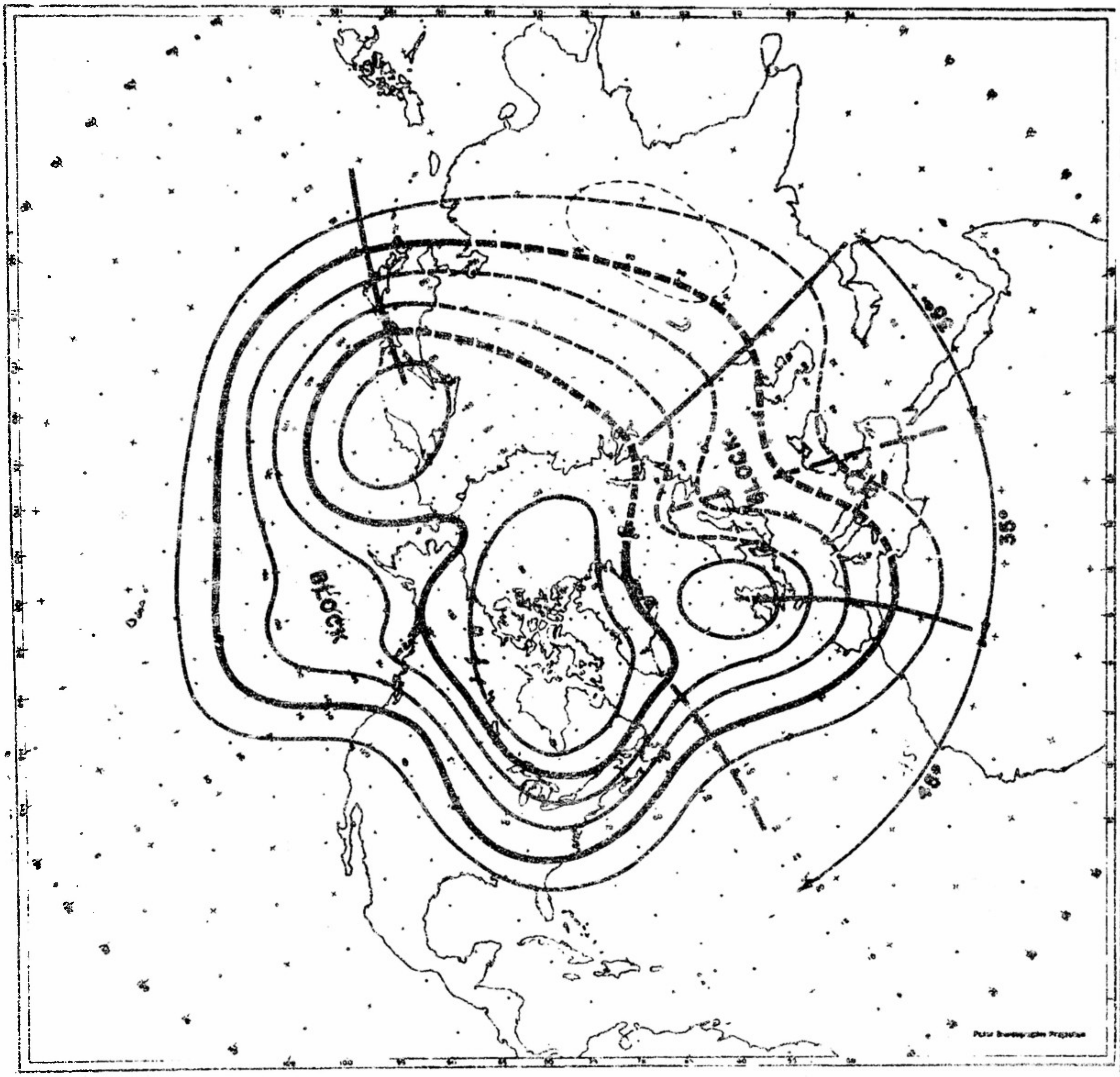
Example 5 : Figure 5

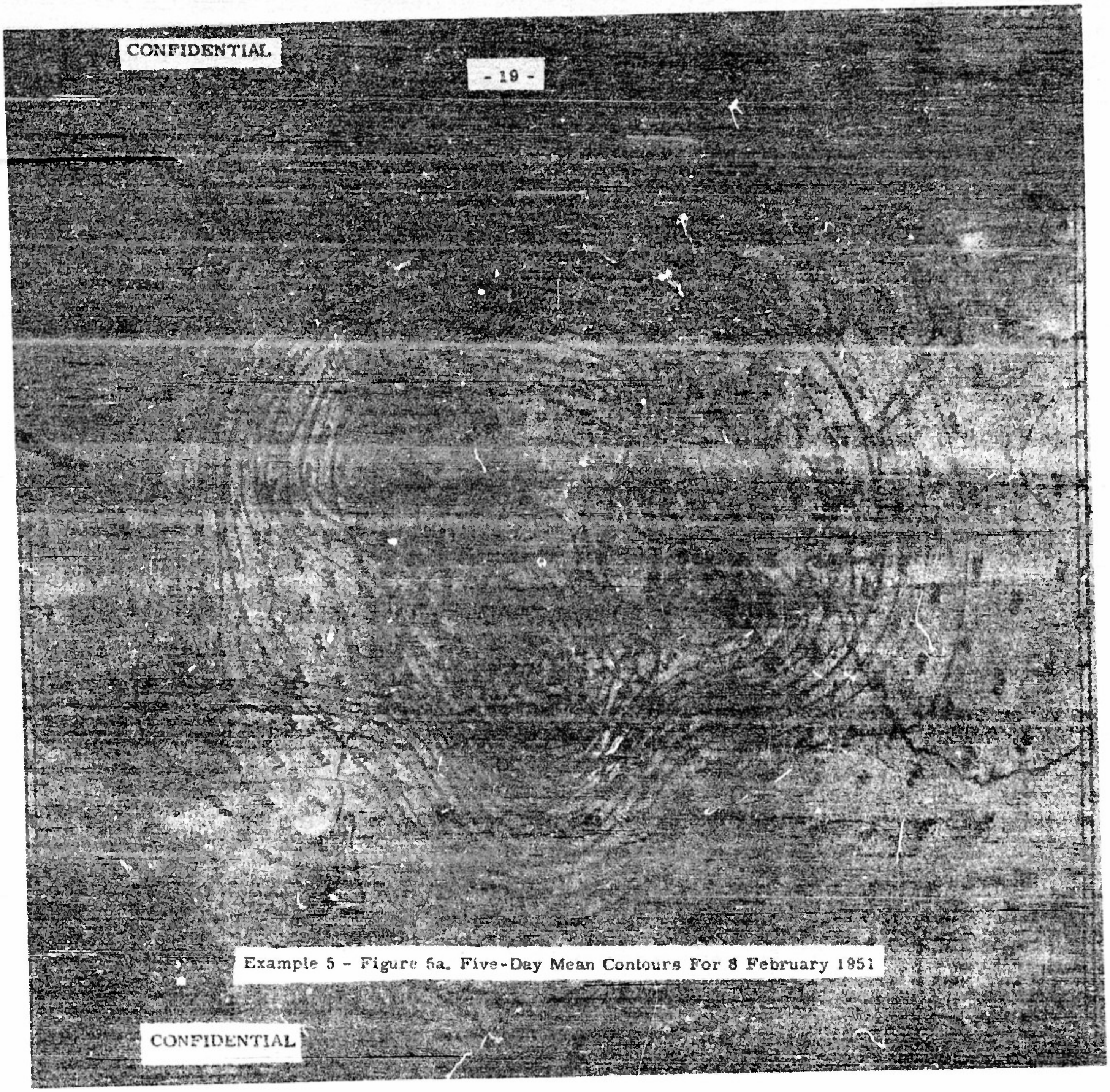
With a block in the Pacific and none in the Eastern Atlantic, conditions seem favorable for a block over Western Europe. The anti-cyclonic curvature of the contours over Greenland strengthens this hypothesis. (Rule 14)

Although the half wave length in the Eastern Atlantic is 45°, a shorter wave length of 35° is used in approaching and leaving the block. (Rule 3). The flat zonal pattern is then extended to the East Asia trough.

Figure 5a: This was a difficult chart. Differences occur principally in the shape of the block.



Example 5 - Figure 5. Extended Mean Contours For 8 February 1951



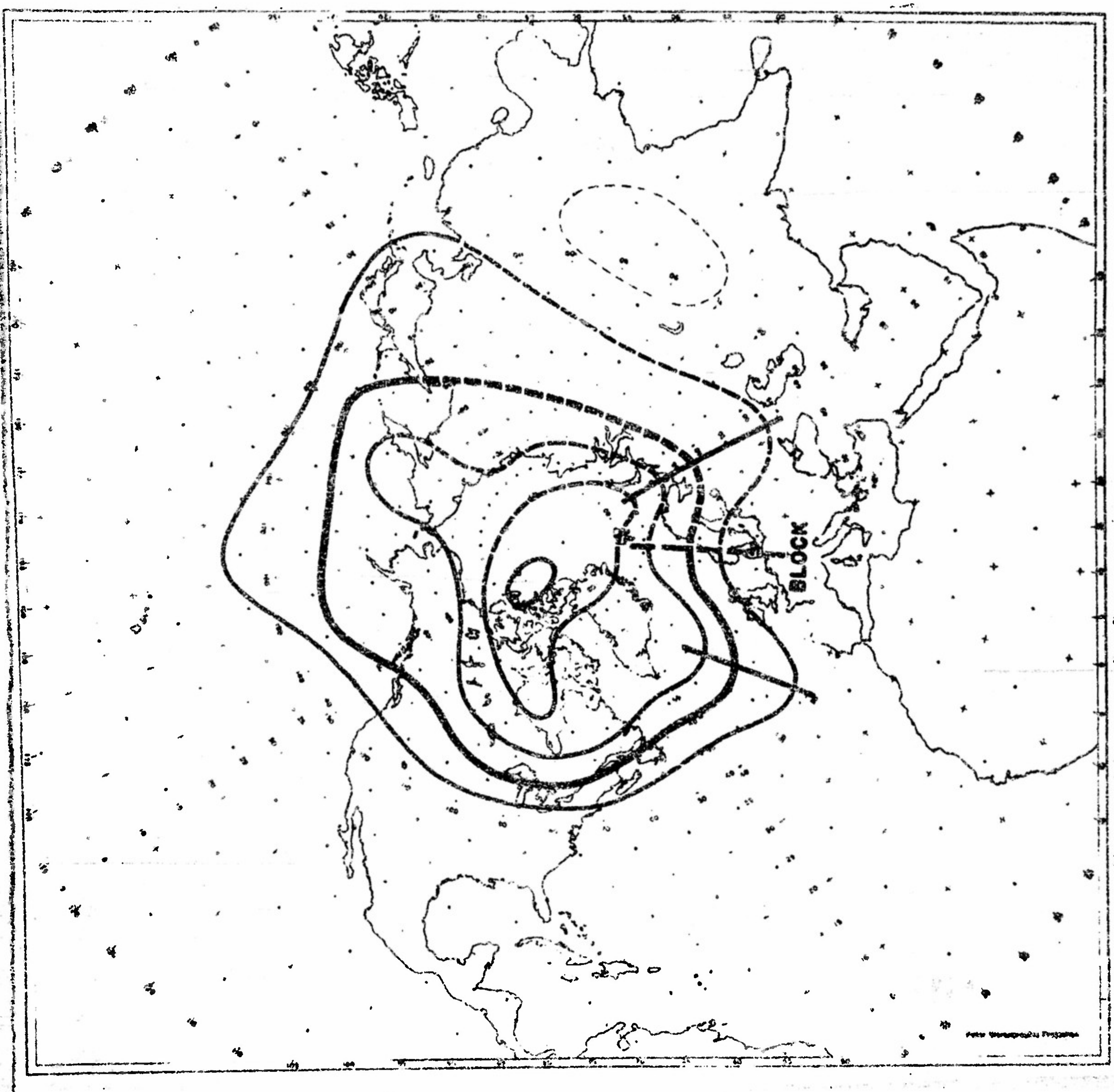
Example 5 - Figure 5a. Five-Day Mean Contours For 8 February 1951

Example 6 : Figure 6

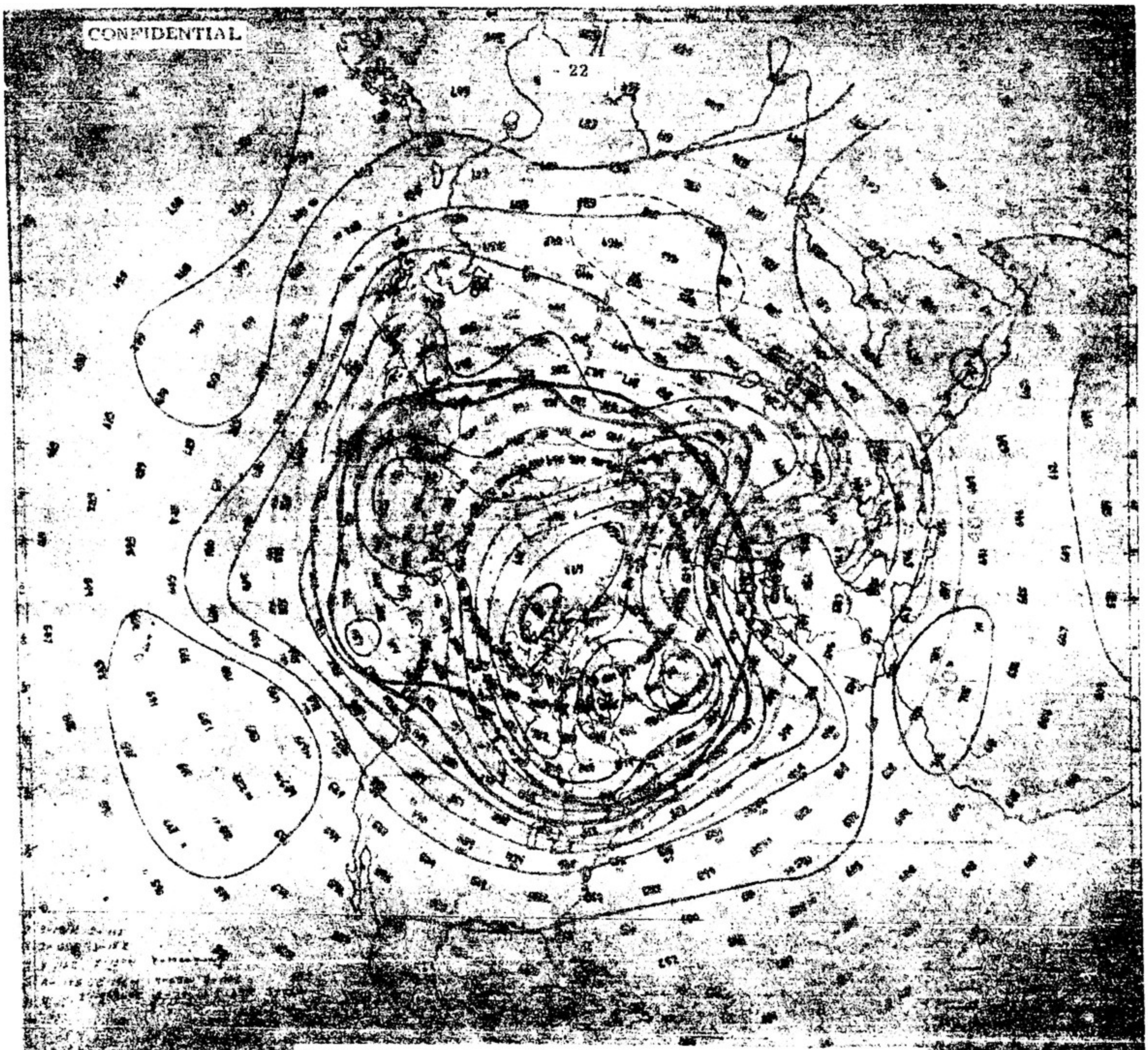
The usual considerations of symmetry establish a block over Western Europe and a trough over Russia. (Rule 2)

Weak zonal flow is extended downstream to the trough over the East Asian coast.

Figure 6a: Again about as close to the actual flow as should be expected.



Example 6 - Figure 6. Extended Mean Contours For 21 June 1950



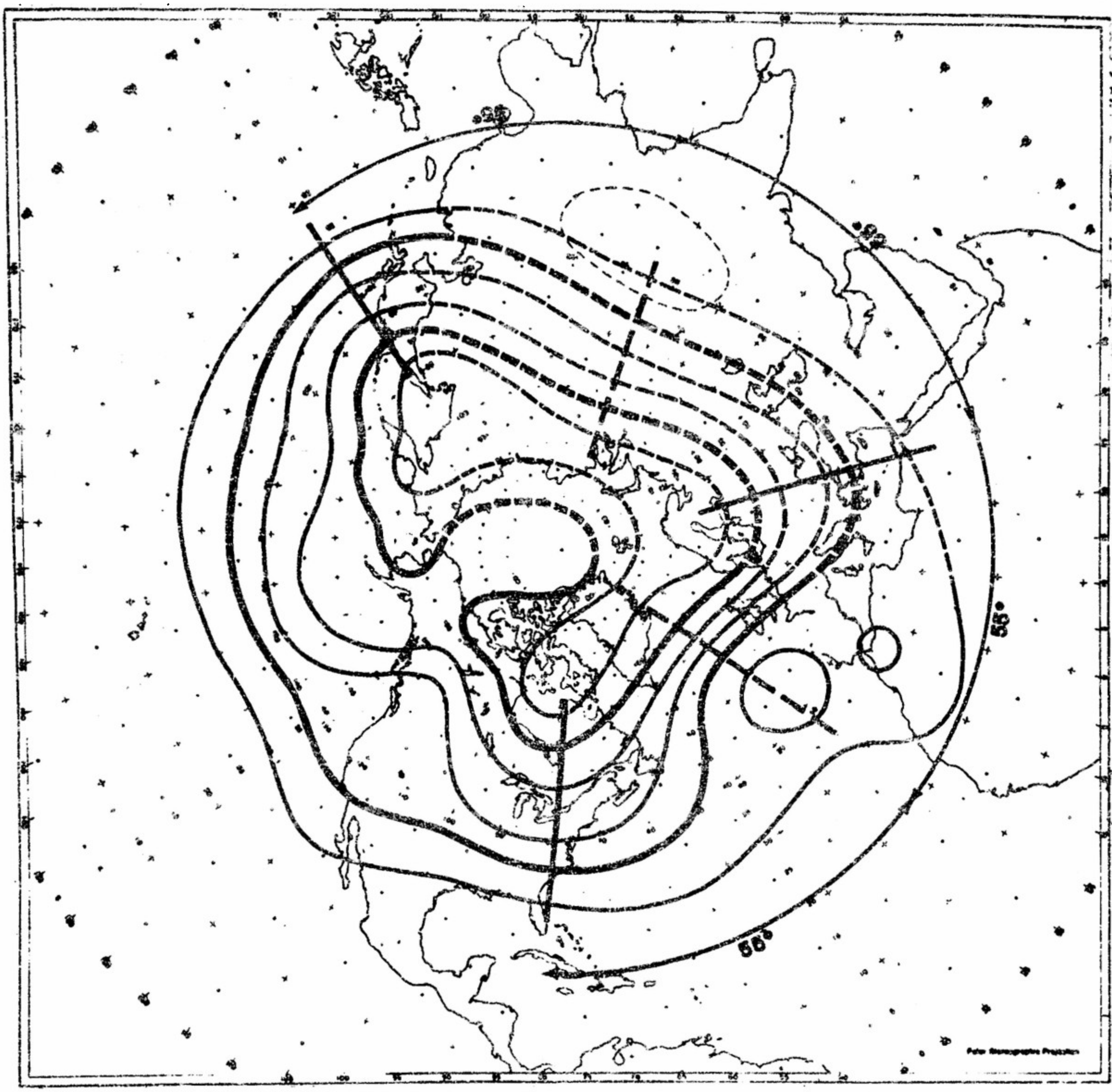
Example 6 - Figure 6a. Five-Day Mean Contours For 21 June 1950

Example 7 : Figure 7

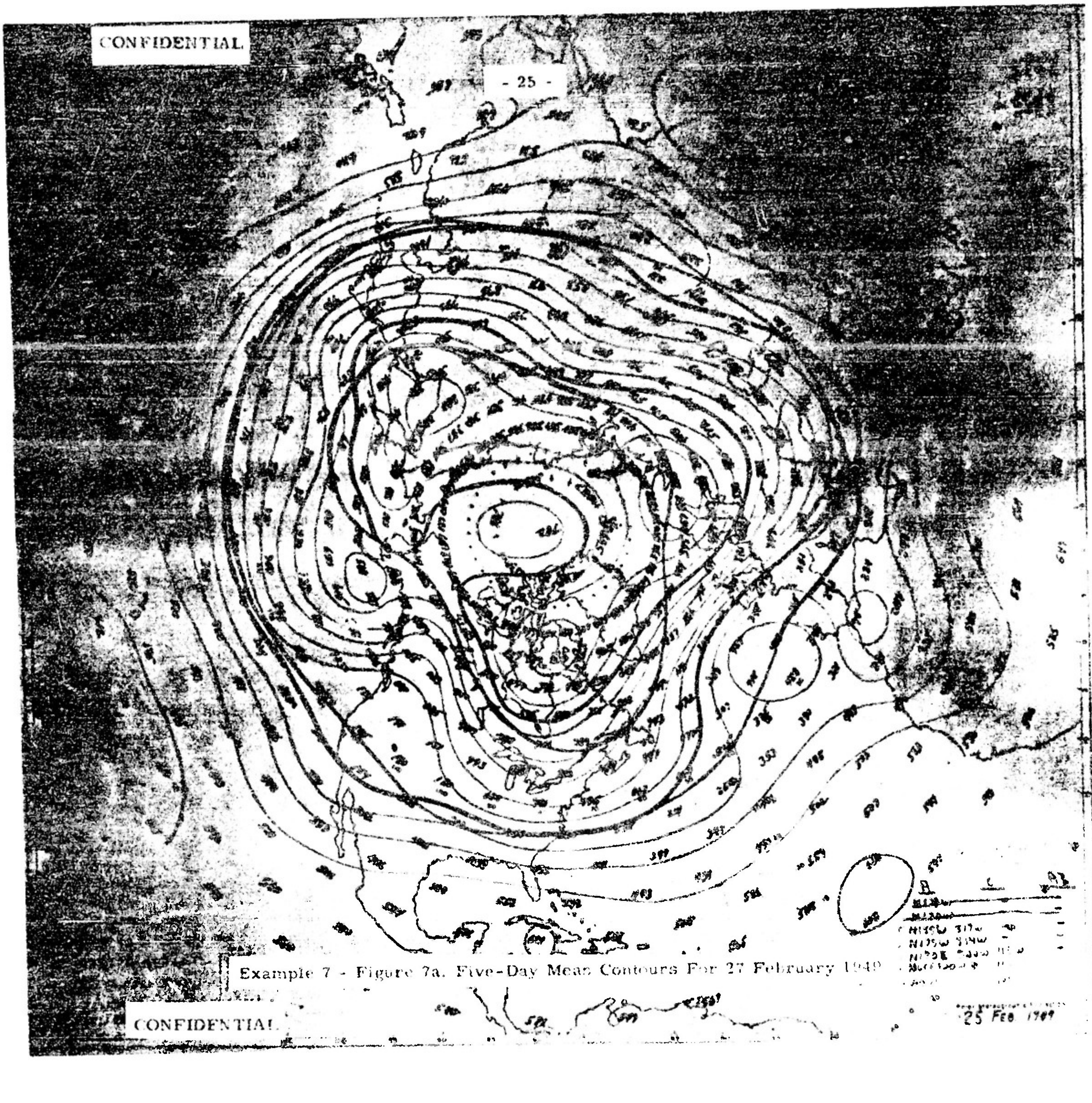
The deep trough over Western Europe makes impossible a block over Asia. (Rule 6)

The distance from the trough over North America to the ridge over the Eastern Atlantic measures 55°; this half wave length establishes a trough at 30° E and a weak ridge at 85° E.

Figure 7a: Small errors in the tilt of the trough and ridge over Asia are difficult to avoid.



Example 7 - Figure 7. Extended Mean Contours For 27 February 1949



Example 7 - Figure 7a. Five-Day Mean Contours For 27 February 1949

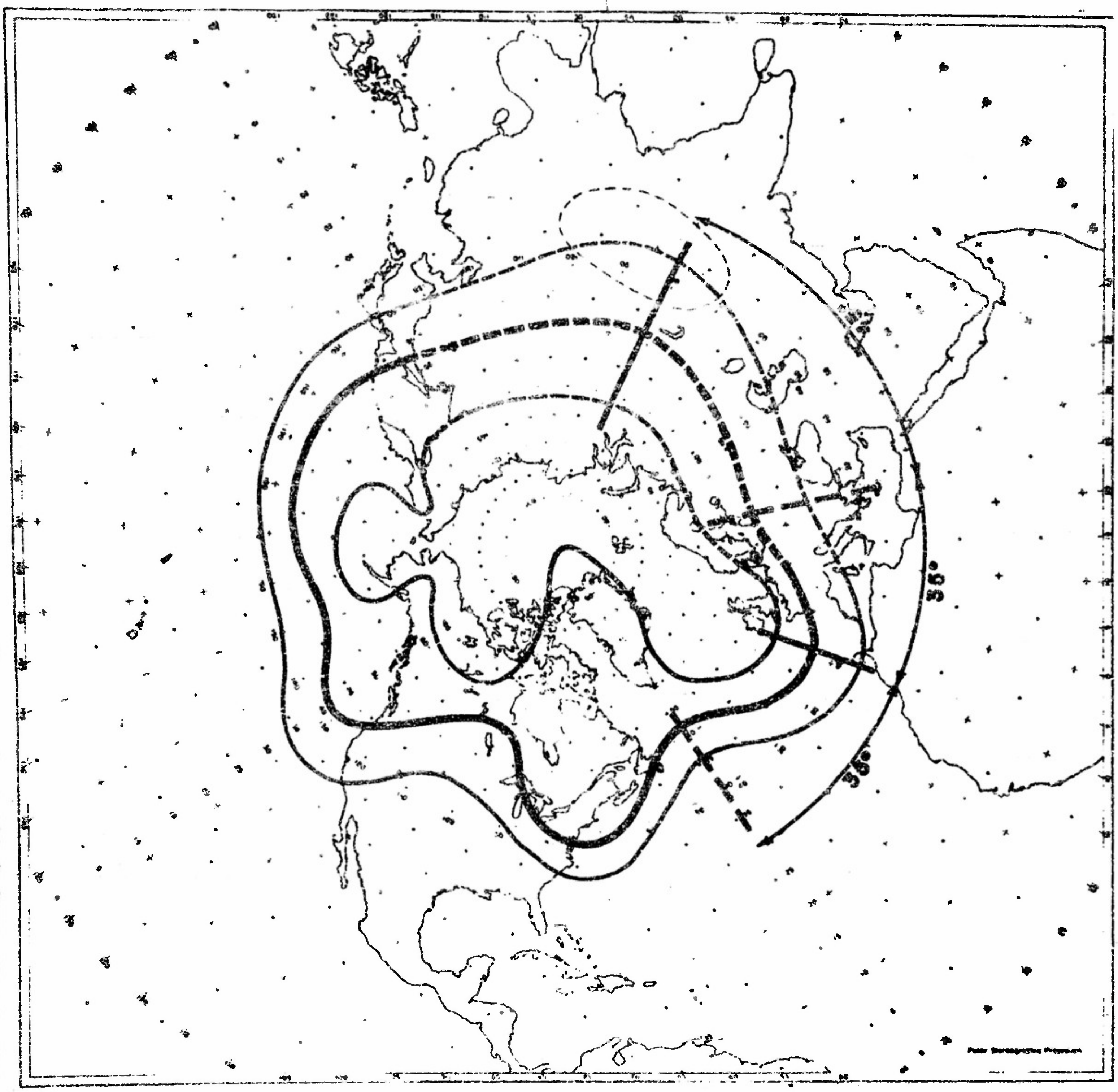
Example 8 : Figure 8

The presence of a deep trough over Britain makes impossible a block over Asia. (Rule 6)

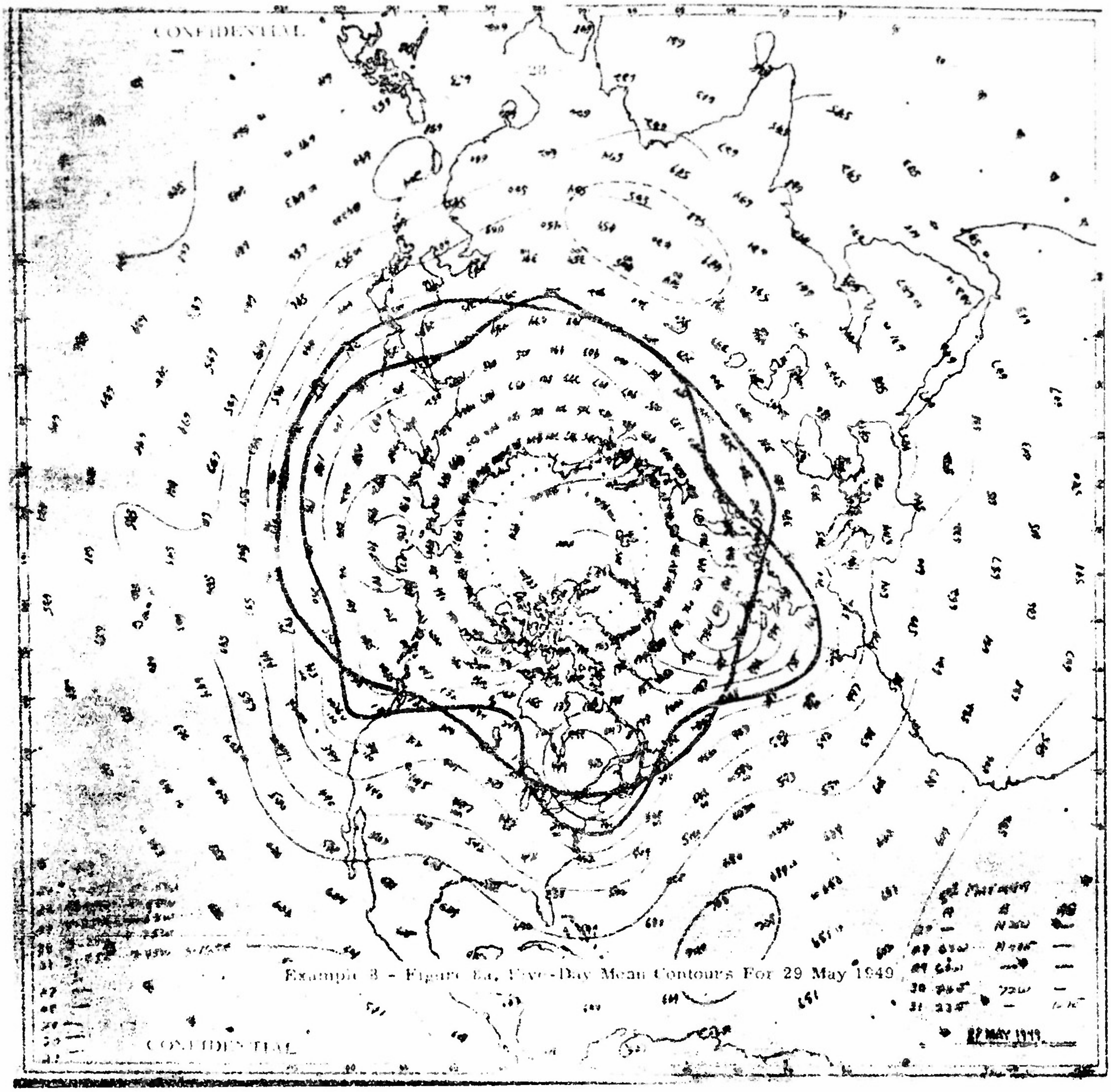
The Atlantic half wave length (35°) establishes a ridge at 25° E.

A longer half wave length (45°) is used to locate the Mid-Asian trough.

Figure 8a: The methods applied did not work well; splitting of the contours over Western Europe was not anticipated.



Example 8 - Figure 8. Extended Mean Contours For 29 May 1949



Example 3 - Figure 8a, Five-Day Mean Contours For 29 May 1949

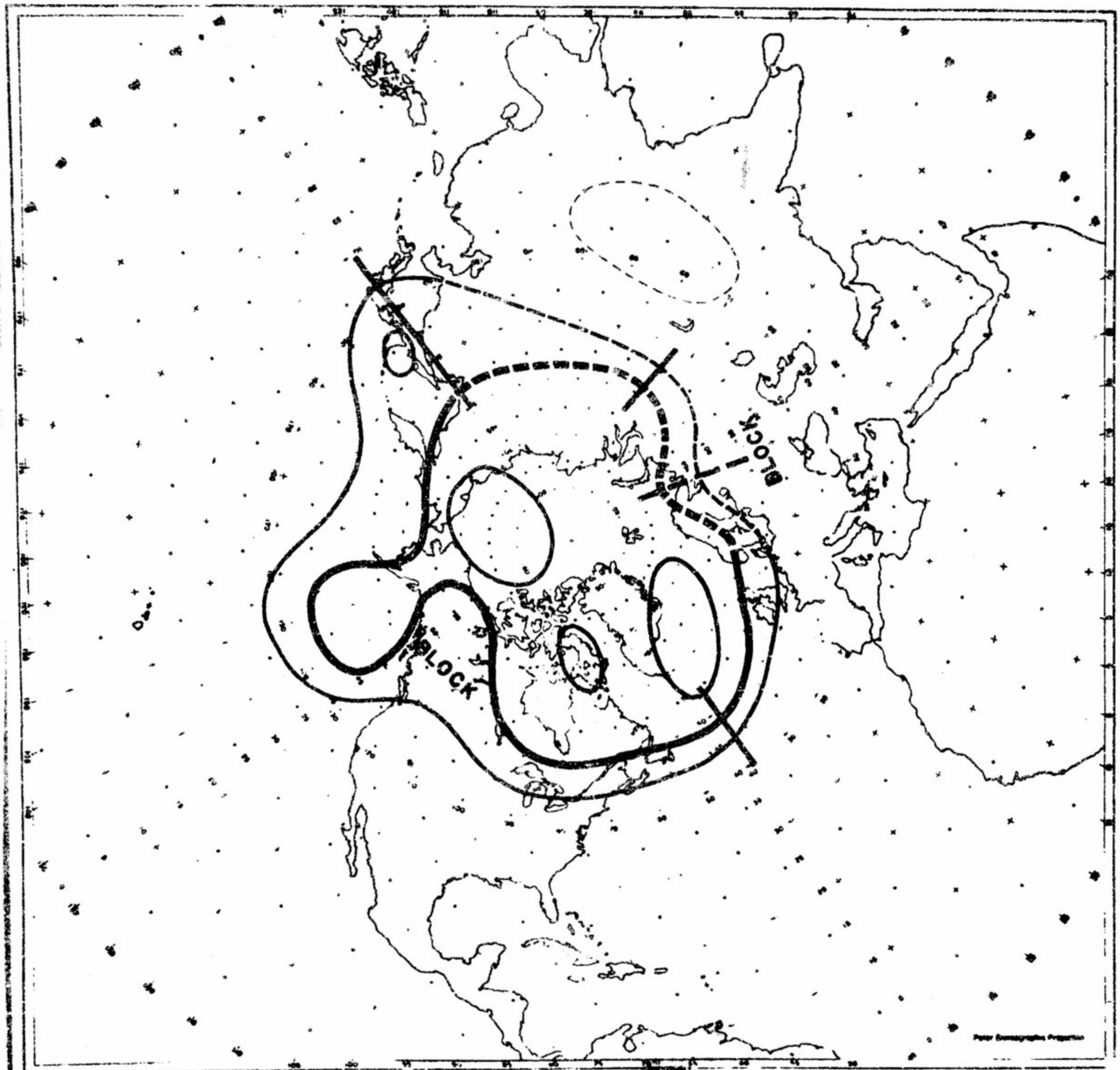
Example 9 : Figure 9

With a block over northwestern Canada and none in the Atlantic, a block over the Eurasian continent is certain. (Rule 14)

The trough over the Eastern Atlantic places the block over Europe rather than Asia.

The rest of the extended flow is probably zonal. (Rule 5)

Figure 9a: Considering the difficulty of the pattern, verification is good.



Example 9 - Figure 9. Extended Mean Contours For 27 June 1950

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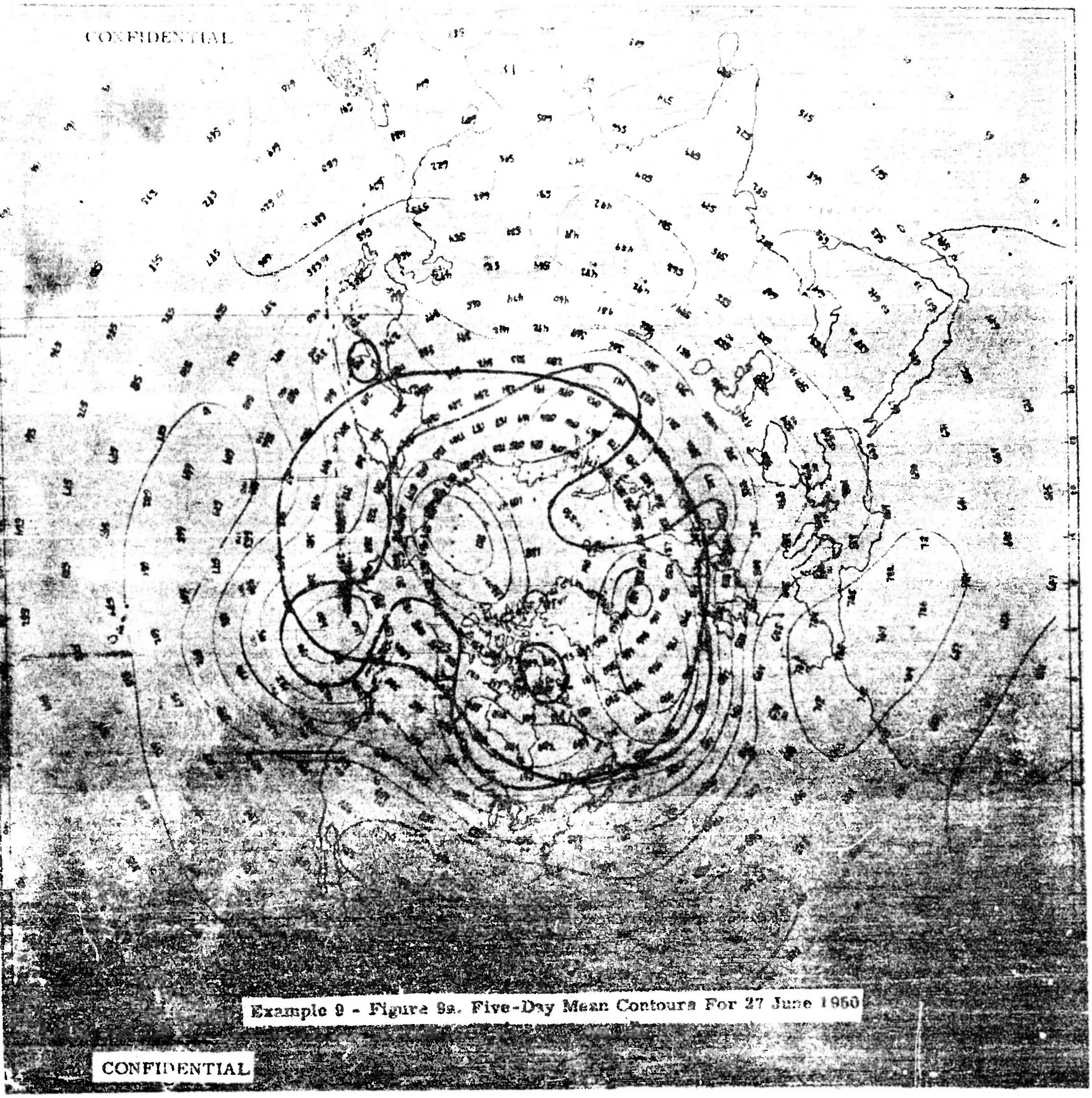

Example 9 - Figure 9a. Five-Day Mean Contours For 27 June 1960

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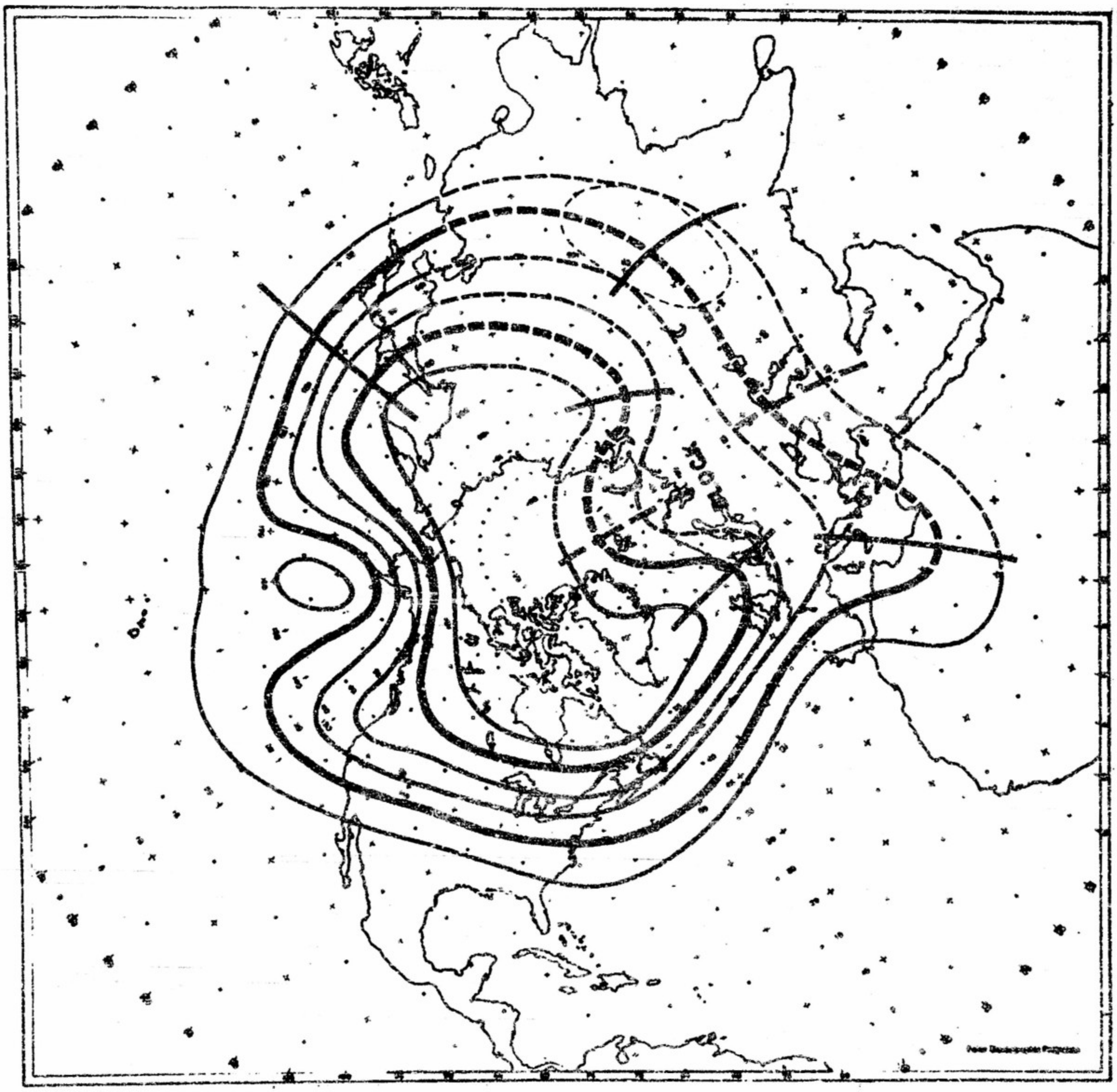
Example 10 : Figure 10

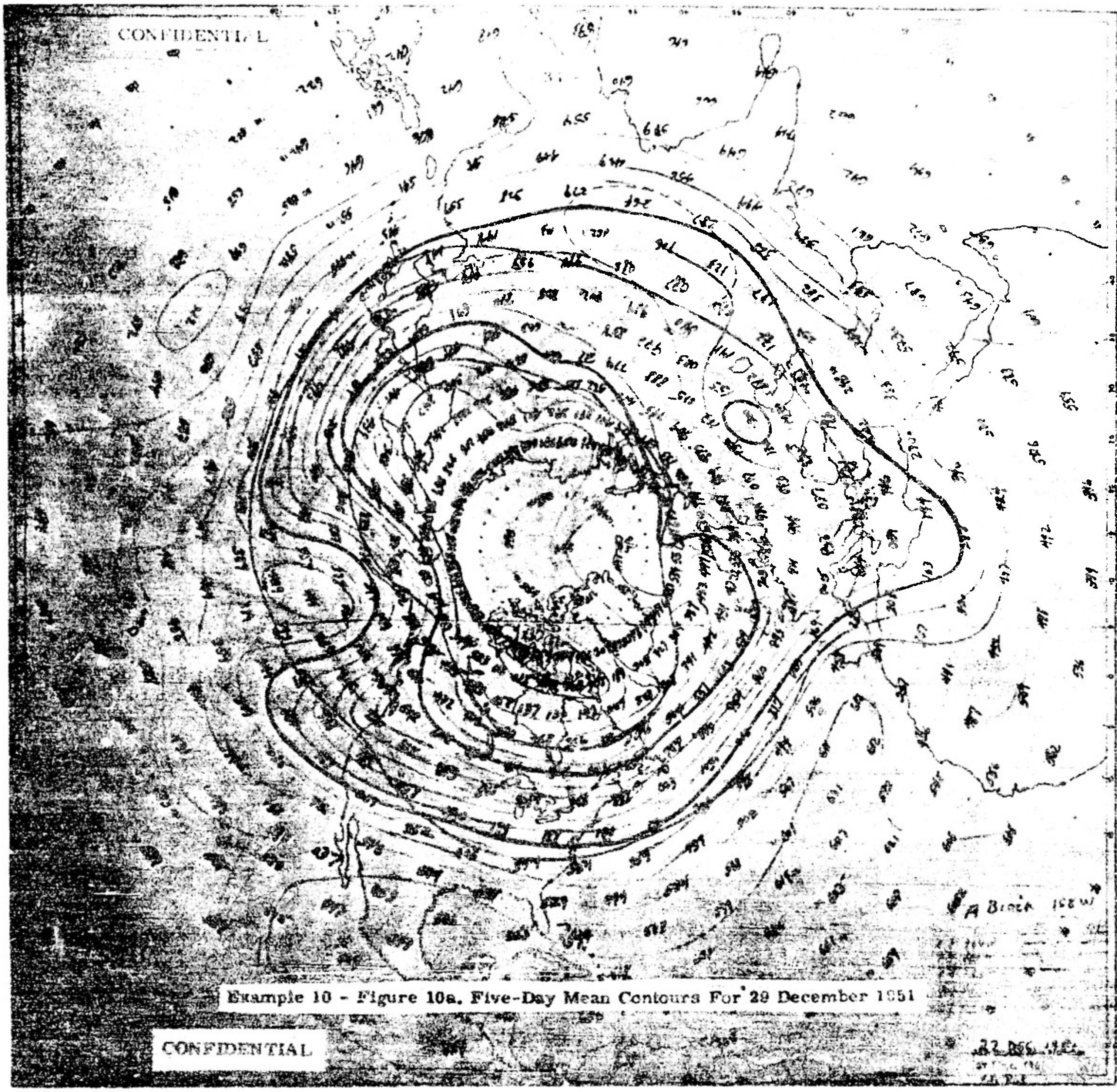
A split in the contours approaching Europe and a strong block over the Eastern Pacific establish a B-type block over Western Europe. (Rule 14)

Downstream flow is probably zonal. (Rule 5)

Figure 10a: The blocking high near the Caspian Sea was not foreseen. If reports from the Mediterranean become unavailable, this area may prove difficult to handle.



Example 10 - Figure 10. Extended Mean Contours For 29 December 1951



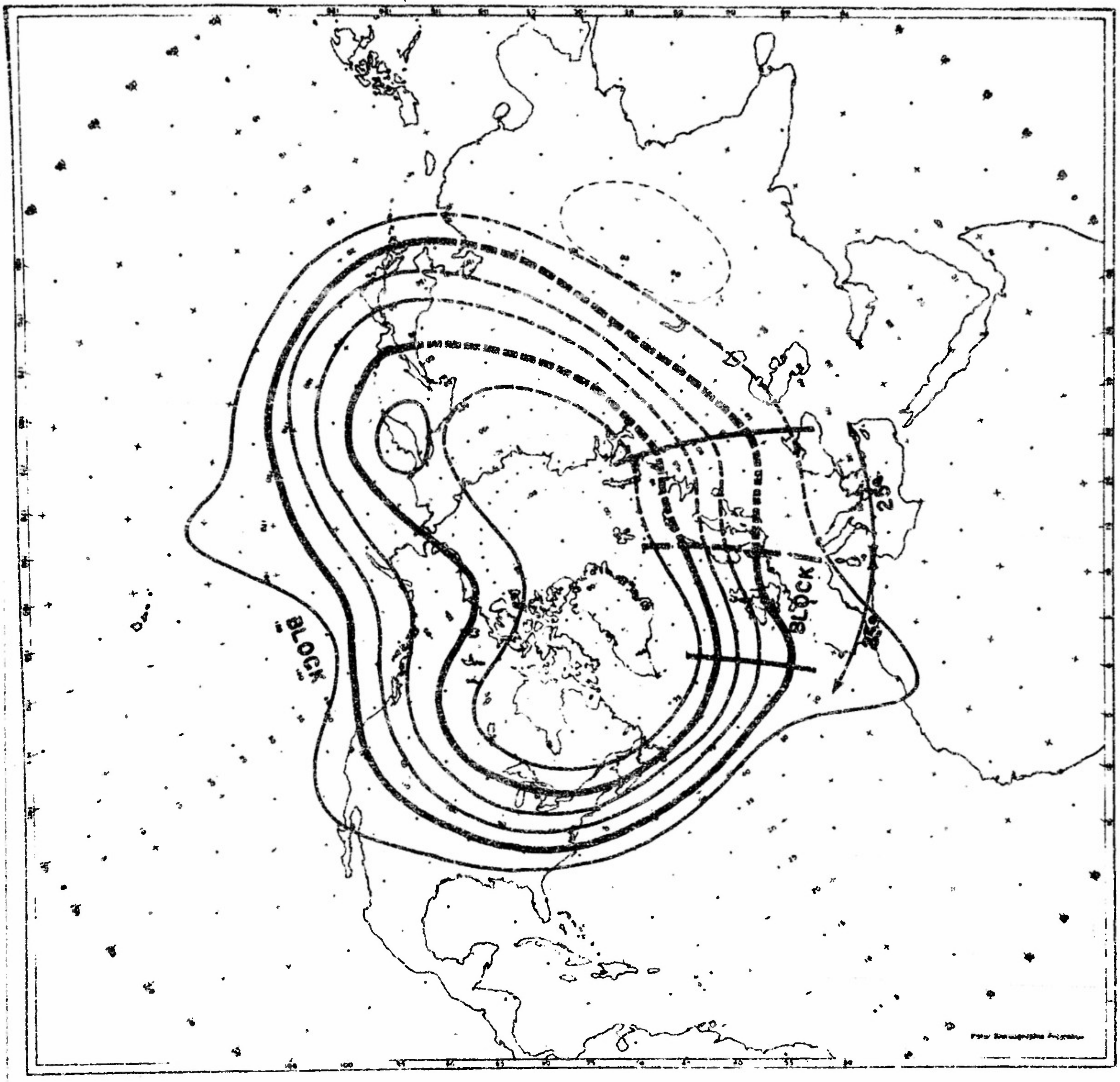
Example 10 - Figure 10a. Five-Day Mean Contours For 29 December 1951

Example 11 ; Figure 11

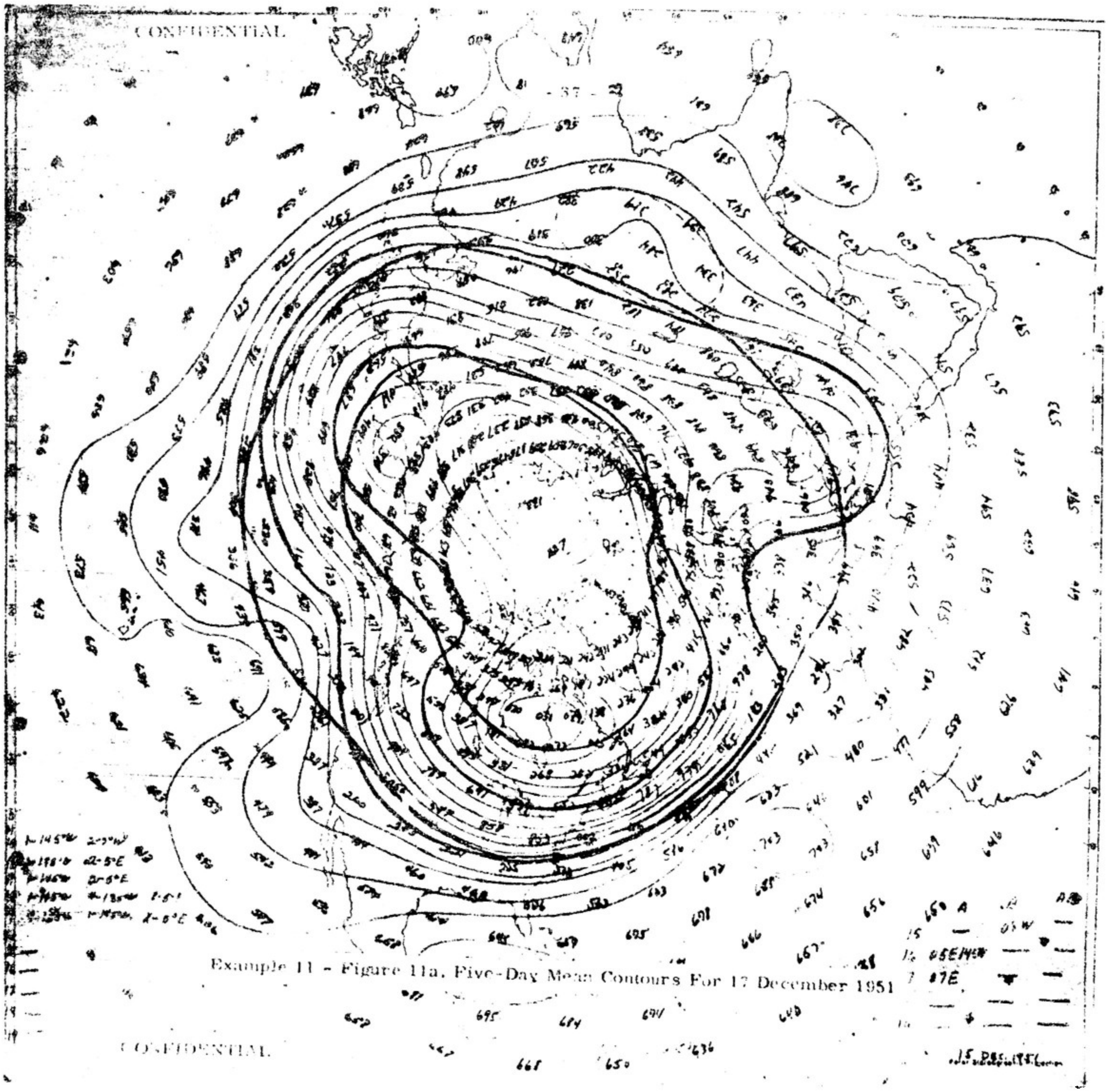
A block is established over Western Europe, and the next trough is located according to the usual considerations of symmetry. (Rule 14; Rule 2)

Zonal flow is extended to Eastern Asia . (Rule 5)

Figure 11a: Verification good, except for the depth of the trough east of the block.



Example 11 - Figure 11. Extended Mean Contours For 17 December 1951



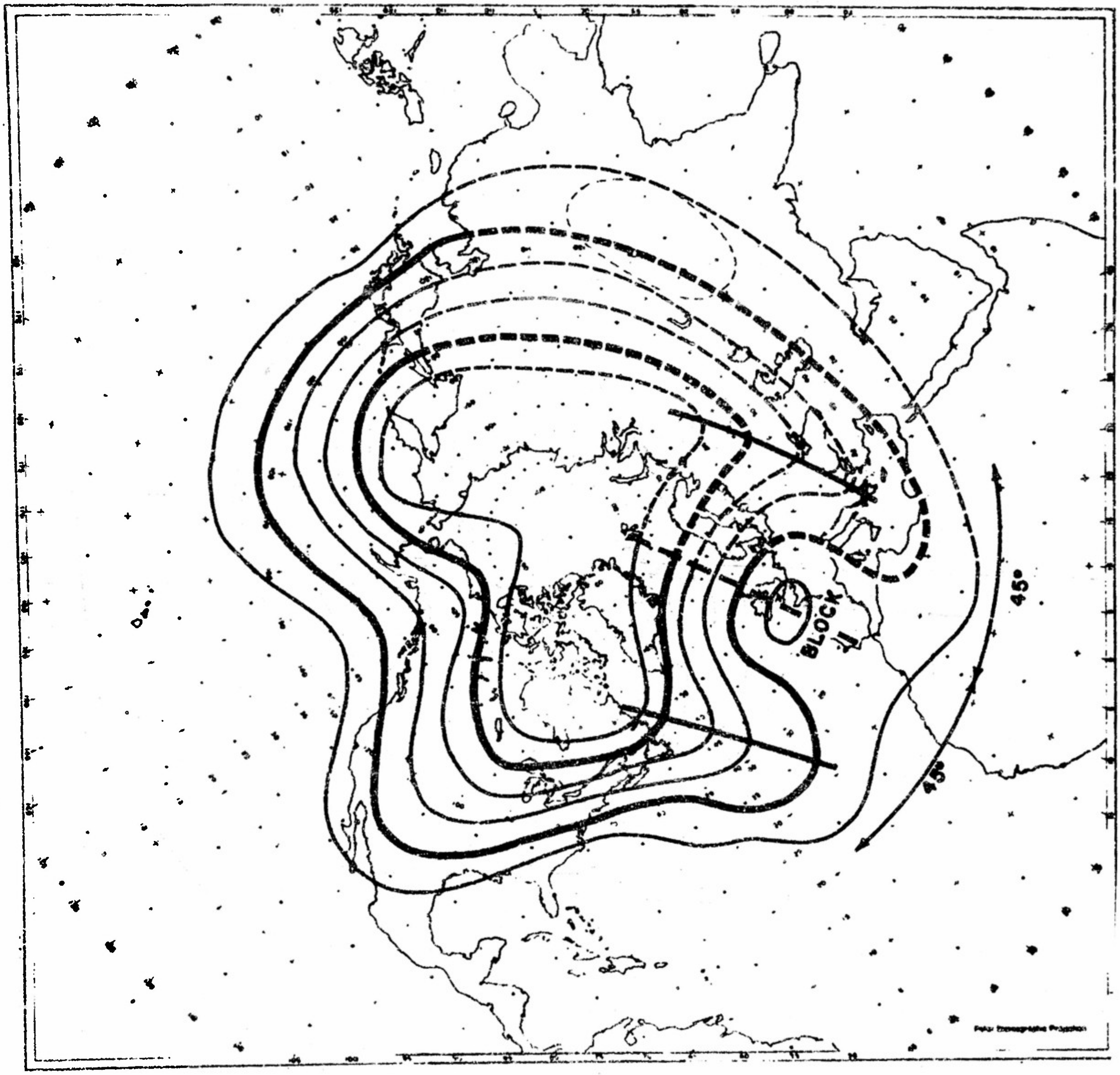
Example 11 - Figure 11a. Five-Day Mean Contours For 17 December 1951

Example 12 : Figure 12

Considerations of symmetry place a trough east of the block over Britain. (Rule 2)

This trough is the most prominent feature over Asia. Zonal flow extends to the East Asian trough. (Rule 5)

Figure 12a: Verification good.



Example 12 - Figure 12. Extended Mean Contours for 30 January 1949

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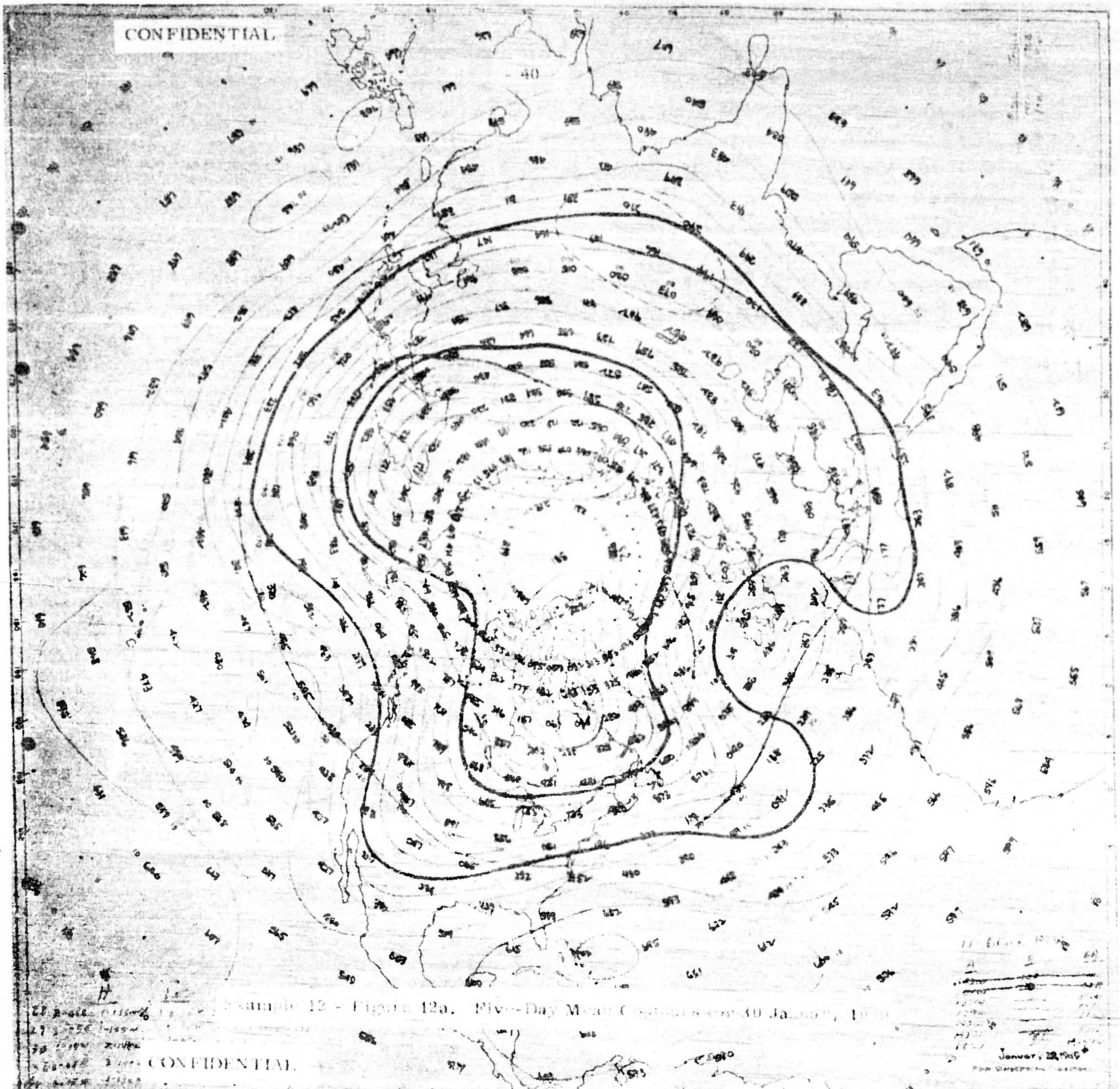

Sample 12 - Figure 12a. Five-Day Mean Contours for 30 January, [illegible]

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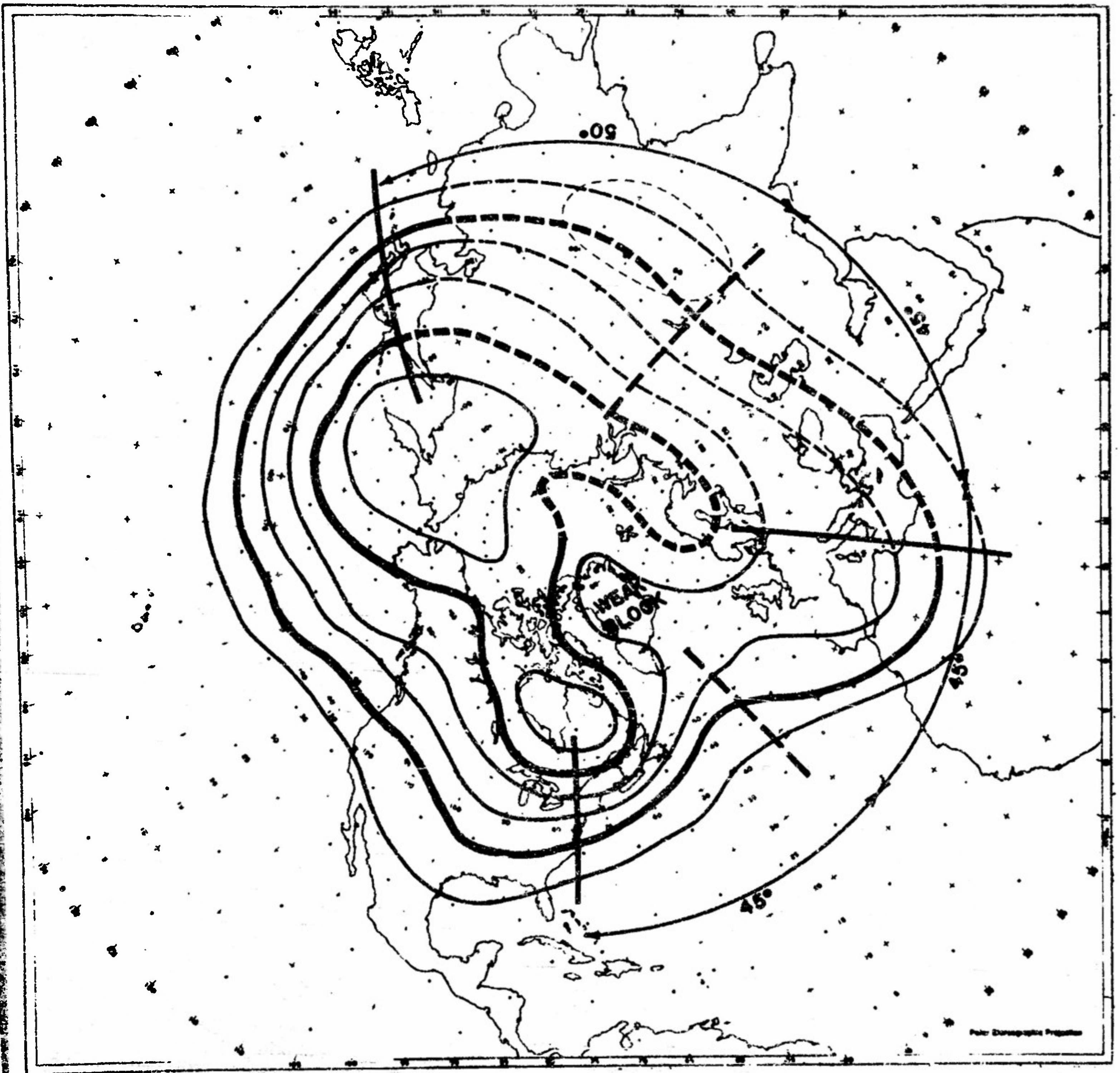
Example 13 : Figure 13

The weak block over Greenland does not prevent this from being a pattern consisting principally of open waves. (Rule 4)

Half wave lengths in the Atlantic fit reasonably a pattern extended through Asia.

The ridge west of the Himalayas is not of large amplitude. (Rule 6)

Figure 13a: The extension is satisfactory.



Example 13 - Figure 13. Extended Mean Contours for 28 December 1950

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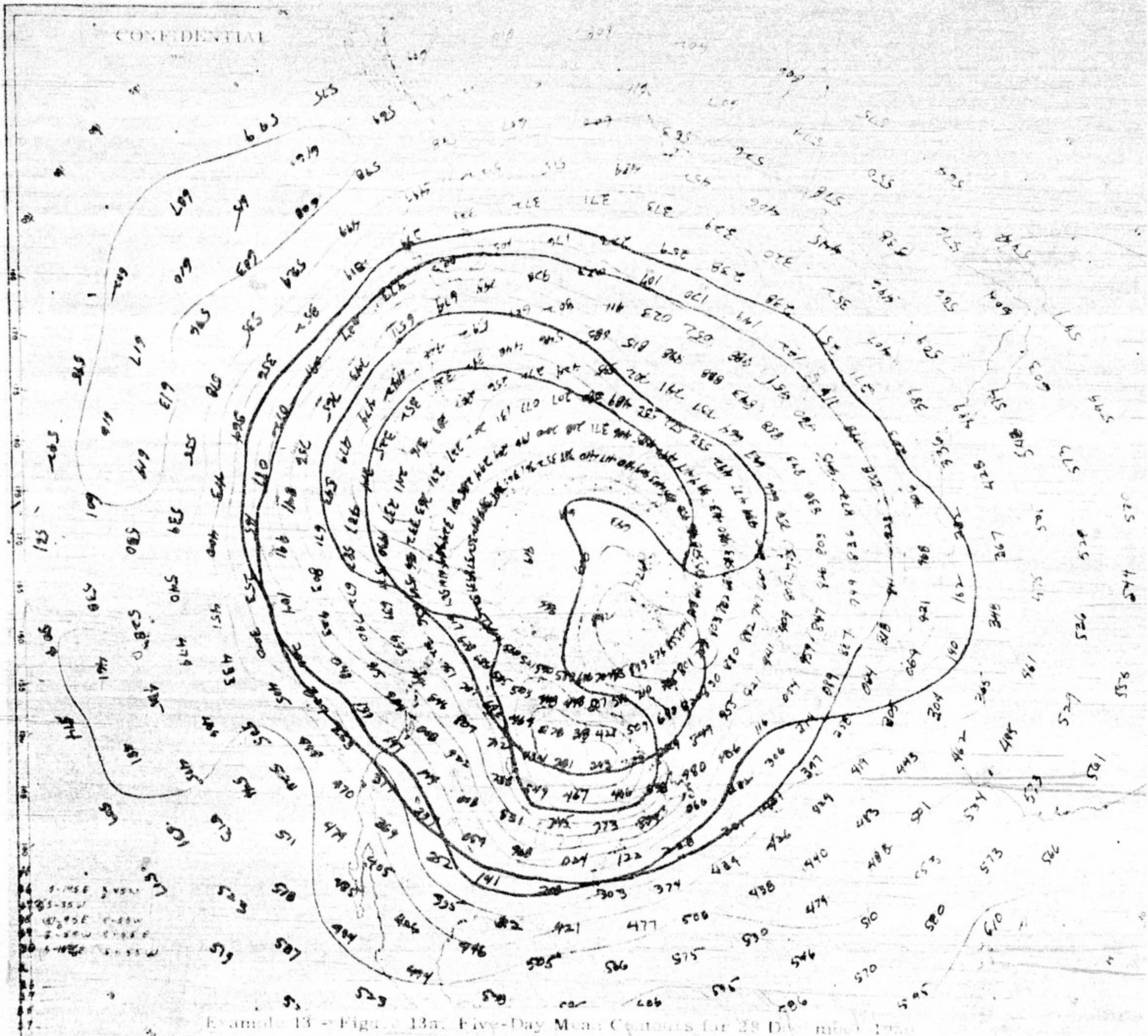

Example 13 - Figure 13a. Five-Day Mean Contours for 28 December 1950

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28 DEC 1950

CHAPTER II. PRESENT CONCEPT OF PRESSURE-HEIGHT FORECAST PROBLEM

1. Outline

This report has developed a method of forecasting pressure-heights in areas supplying no meteorological information. As has been shown, this method consists of first predicting pressure-height at the 500-mb level and then extrapolating upward and downward from that point. (Part of this technique, that giving the required large-scale distribution of height values, was outlined in Volume II, while the extrapolatory process was detailed in Volume I.) This chapter will sketch current research on the pressure-height problem, research necessarily based on two hypothetical situations: (1) where the reception of data from Eurasia has been but recently interrupted and (2) where data has been unavailable for some time.

2. Full Data and Extrapolation

Should the present flow of data from the Eurasian area be interrupted, the consideration that large-scale features of the mean-flow change but slowly with time (cf. Volume II) and requirements of utmost accuracy would warrant basing the forecasts made within the first week or two on an extrapolatory method rather than on a method designed for silent conditions.

Within the larger framework of this problem the following specific topics continue under investigation:

(1) Surface synoptic developments.

(2) Computation of vorticity charts for the 500-mb level — an attempt to specify conditions at that level for several days after data has not been received. (This study is being conducted at Aerophysics Research Foundation.)

(3) Integration of aircraft reports of completed flights with analyses prepared for silent areas.

(4) Preparation of methods for the in-flight checking and changing, where required, of pressure-height forecasts.

3. Silent Conditions

While research already completed has made possible satisfactory forecasts for the 500-mb lev l (18, 280 feet) under all conditions, the present program, concentrated on surface features, should improve downward extrapolation. Specific elements of this program are as follows:

(1) Processing required readings of surface pressure for each day of the historical series (1945 through 1952).

(2) Examining the relation between surface pressure changes and changes in height of the 500-mb level.

(3) Categorizing behavior of surface systems according to the basic upper-air pattern.

(4) Examining those synoptic situations causing extremely high or extremely low surface pressure.

The aim of these investigations is the development of an objective routine for forecasting pressure-heights, a routine to be based on several analytic procedures, like those discussed in Volume II. A possible method might involve combining procedures applicable to the 500-mb level with those applicable to surface conditions, and modifying the result by post-flight or in-flight observations.

III. ESTIMATE OF ACCURACY OF PRESSURE-HEIGHT FORECASTS

The results of the operational research conducted on this task provide three methods of pressure-height determination for varying conditions of data availability. A brief discussion of each, the conditions under which they are to be utilized and the estimated accuracy are contained herein.

1. Computation Utilizing the Pastagram

When meteorological information at the surface and aloft in the desired prediction area is available, a pressure-height computation utilizing the Pastagram is feasible. This computation is rapidly and easily performed. The average error expected would ordinarily be less than 20 feet, and the maximum error would not exceed 50 feet unless the technique were incorrectly applied.

The procedure for applying the Pastagram to pressure-height computations is outlined in NAVAER 50-IP-501, Use of the Pastagram in Pressure-Height Computation, prepared at AROWA and included as Appendix A to the First Progress Report on this task. Detailed examples of this technique are included therein for each of several anticipated types of computation.

Aircraft of the Heavy Attack Training Unit based at Norfolk, Virginia are undertaking a series of operational tests utilizing the Pastagram to perform pressure-height computations on meteorological data obtained in flight. Tests to ten and fifteen thousand feet have proven accurate and feasible.

The first flights indicated the necessity of having properly calibrated thermometric units and pressure altimeters in the aircraft. The large errors were direct results of uncalibrated instruments. After these instruments were calibrated, the average error was 32 feet at the 10,000-foot level. The maximum error at this level was 120 feet. Errors at lower levels were smaller.

Aircraft from this unit are currently testing the application of the technique to obtain pressure-height computations from in-flight data to and above the tropopause.

2. Use of Normal Pressure Altitude Charts

In the absence of any meteorological information relating to the desired forecast area, the pressure-height prediction will be based on values obtained from climatological normal pressure altitude charts. The accuracy of the prediction obtained from these charts is a function of the variability of the height above the normal value. This, in turn, is a function of geographical location, season, and the height for which the prediction is required. Figure (2) of Volume I of this report indicates the seasonal and geographic variability of the heights, about a median value, of the 500-mb surface. In general, errors will be least over tropical maritime areas and in summer months. They may be expected to be greatest over mid-continental areas and during winter months. The variability appears to be a minimum near the 5000-foot level and to increase upward and downward from that level.

To provide numerical values for this prediction, Project AROWA has prepared NAVAER 50-IC-501, Normal Pressure Altitude Charts for the Northern Hemisphere, which was included as Appendix (1) to the Second Progress Report on this project. This set of charts provides the climatological value of pressure altitude at any desired geometric height from the surface to 10,000 feet for any day of the year for all points in the Northern Hemisphere.

A possible source of error in the values obtained during winter months over mid-continental areas at 3000 to 8000 feet from these charts due to a meteorological assumption of linear rate of change of "D" with altitude was suggested by personnel of the Air Weather Service. This has been thoroughly investigated, utilizing climatic data obtained over the largest mid-continental area of the globe, central Asia, for the winter months of December, January, and February.

The effect of the non-linearity of the rate of change of "D" through this layer from the observed soundings produced only small differences.

The average difference at 6000 feet is 22 feet. The greatest difference observed at this level was 30 feet. The table below indicates the distribution of average and maximum errors for the three winter months of December, January, and February at each level introduced by the meteorological assumptions involved in the construction of the normal pressure altitude charts. These errors are insignificant in relation to the variability about the normal value.

COMPUTED - OBSERVED NORMAL PRESSURE ALTITUDES
MID-CONTINENTAL AREA - WINTER

Height (feet)	Average Difference (feet)	Maximum Difference (feet)
1,000	1	1
2,000	3	4
3,000	6	11
4,000	10	21
5,000	15	31
6,000	22	30
7,000	16	20
8,000	10	12
9,000	5	6
10,000	2	2

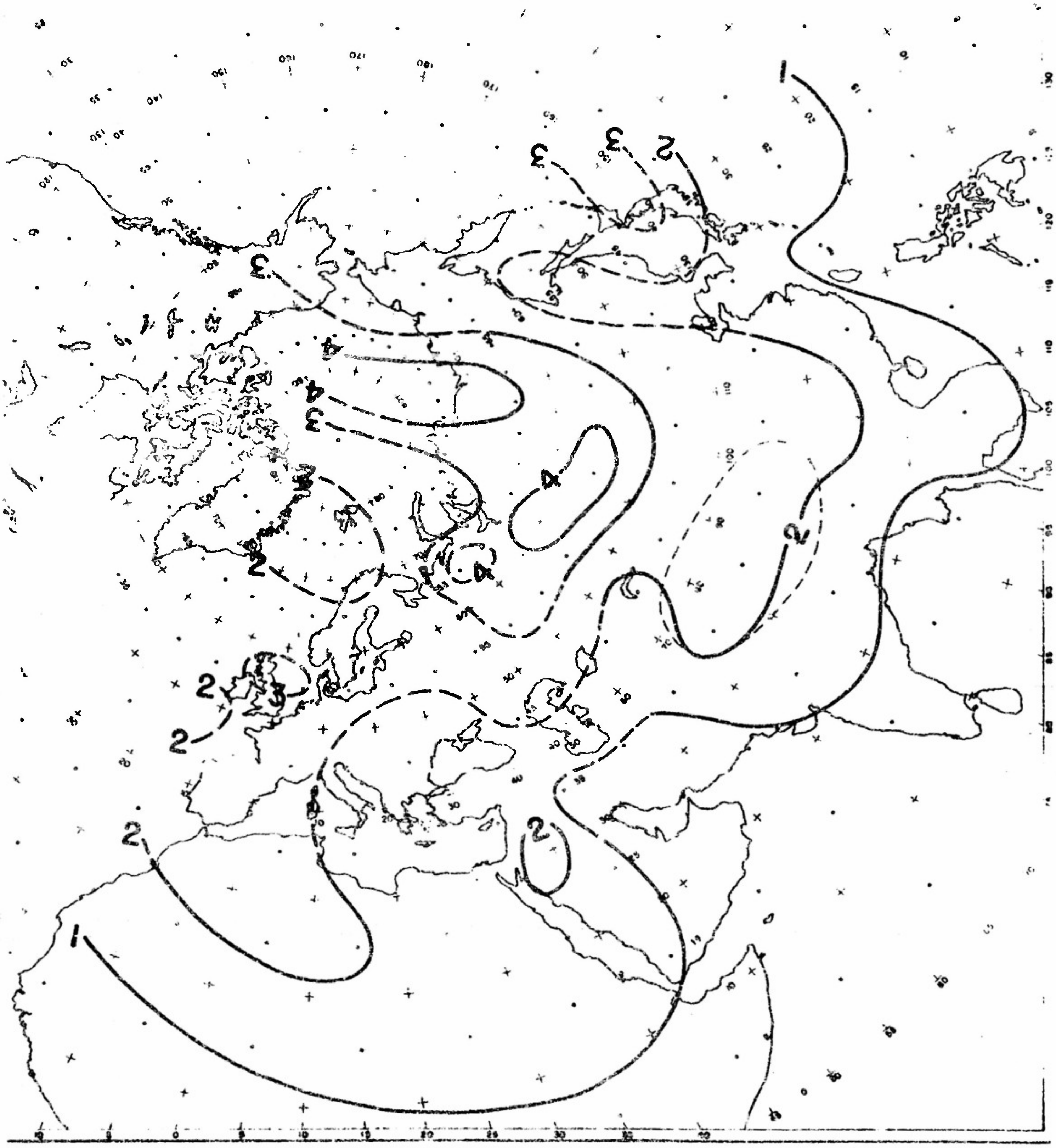
In addition to providing an answer in the absence of meteorological data, the normal pressure altitude charts provide a consistency check for any predicted or computed height.

3. Use of Prediction Scheme for the 500-Millibar Surface and Downward Extrapolation

Application of the procedures outlined in Volume II, Chapter VII and Volume III, Chapter I of this report yields a prediction of the height of the 500-mb surface over an area devoid of, but surrounded by, meteorological data. Limited tests of these procedures have led to the estimate of errors contained here. The results shown here are for 24-hour predictions made without data for the Eurasian continent between the longitudes of 0° eastward to 180°. The values quoted are for the month of April which approximate annual averages. Errors will be larger in mid-winter and smaller in the summer months.

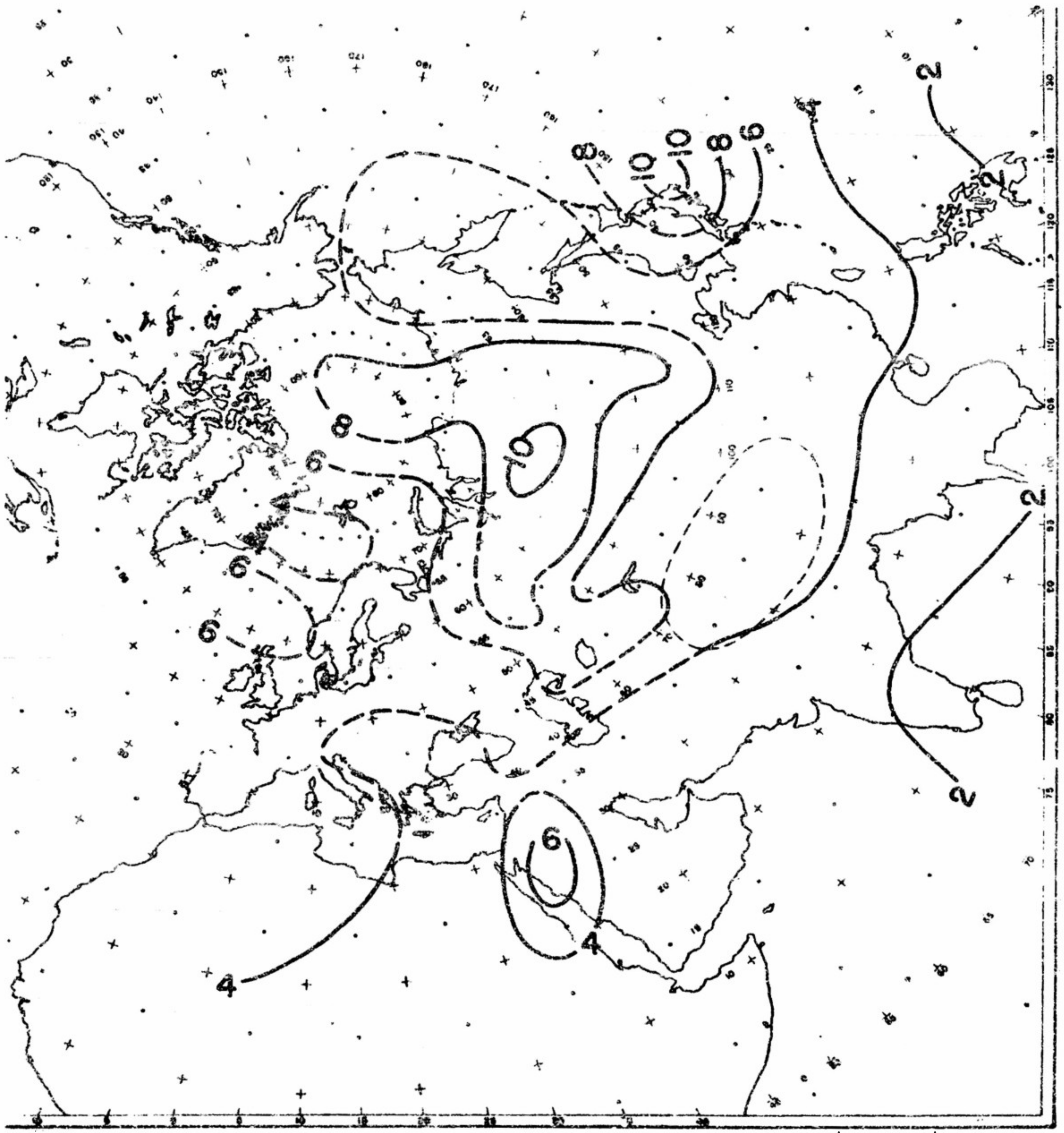
Estimates of the accuracy of this system are shown in Figures (14) and (15). The isopleths drawn on these charts represent the values of error in hundreds of feet which are not exceeded by certain percentages of the forecasts at each point in the Eurasian area. Figure (14) contains the limiting values of the error for 68 percent[1] of the forecasts

1. The charts contain 68 percent and more than 99 percent of the cases because of the relationship between the values thus obtained and the values for σ (sigma) and 6 σ respectively in normal distributions. Examination of the frequency distributions of pressures and pressure altitudes suggests a lack of normality of their distribution over many parts of the Northern Hemisphere, raising some question as to the utility of σ as a measure of reliability.



Isopleths of forecast error in hundreds of feet: 68% of errors are smaller than values shown __________ Actual - - - - - - Estimated.

Figure 14. Forecast Error at 18,280 Feet in April.



Isopleths of forecast error in hundreds of feet: 99% of errors are smaller than values shown ________ Actual - - - - - - - Estimated.

Figure 15. Forecast Error at 18,280 Feet in April.

at 18,230 feet. Figure (15) contains the limiting values of error for more than 99 percent of the forecasts, and may be interpreted as the extreme error. The general accuracy of the forecasting system is shown by a comparison of Figures (14) and (15) with extreme climatological range of heights in April shown in Figure (16).

From the predicted height at 500 mb it is necessary to extrapolate downward to lower levels. Using a simple extrapolation technique from this one predicted point at 500 mb, the error will normally increase with decreasing height. The errors of the present system after this extrapolation are shown in Figures (17) through (22). These charts give the 68 percent and more than 99 percent value of error at the surface, 5000 feet and 10,000 feet. This downward extrapolation is the least accurate part of the present system and the proposed additional research at the surface is designed to improve the accuracy at these lower levels.

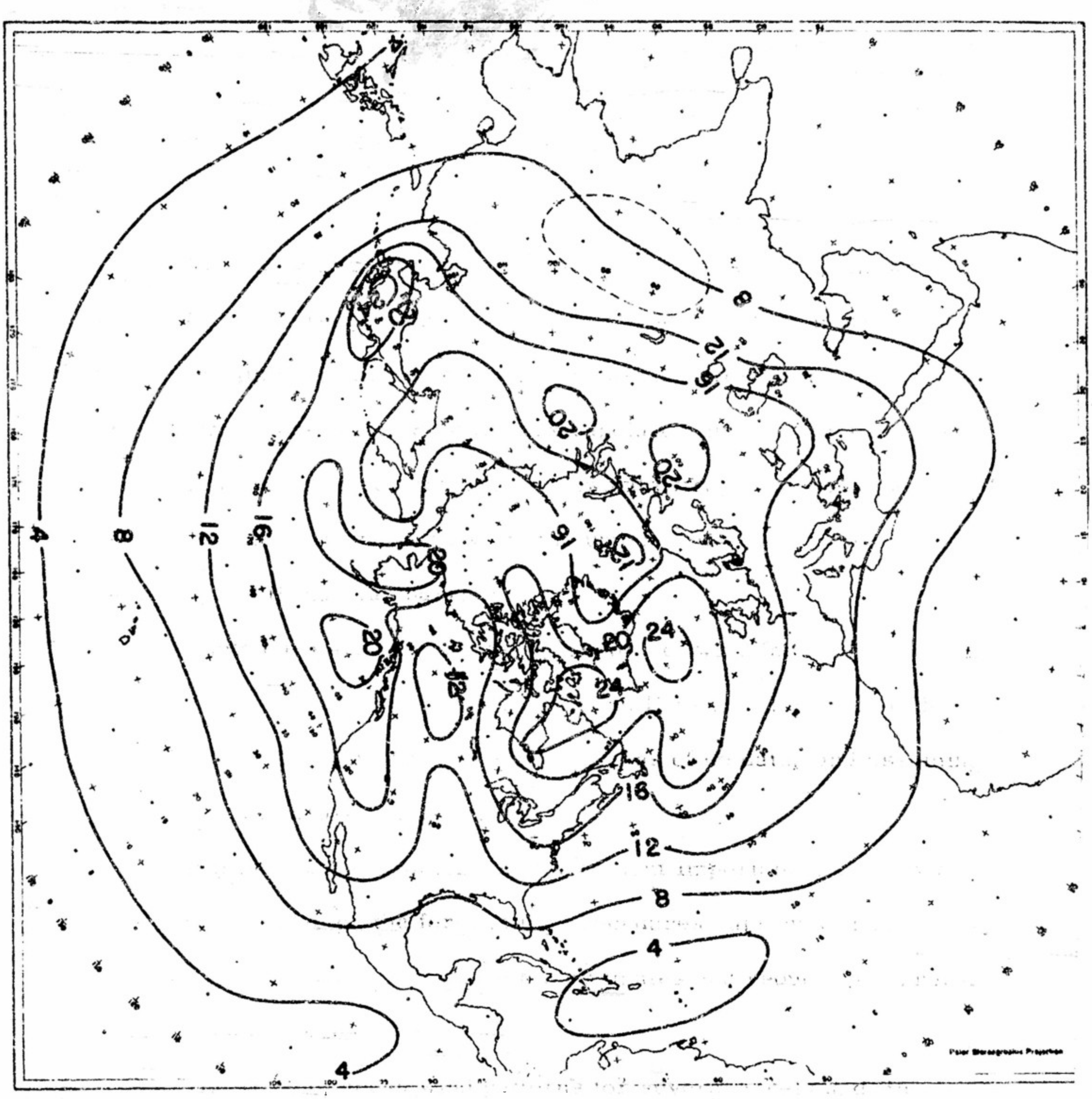
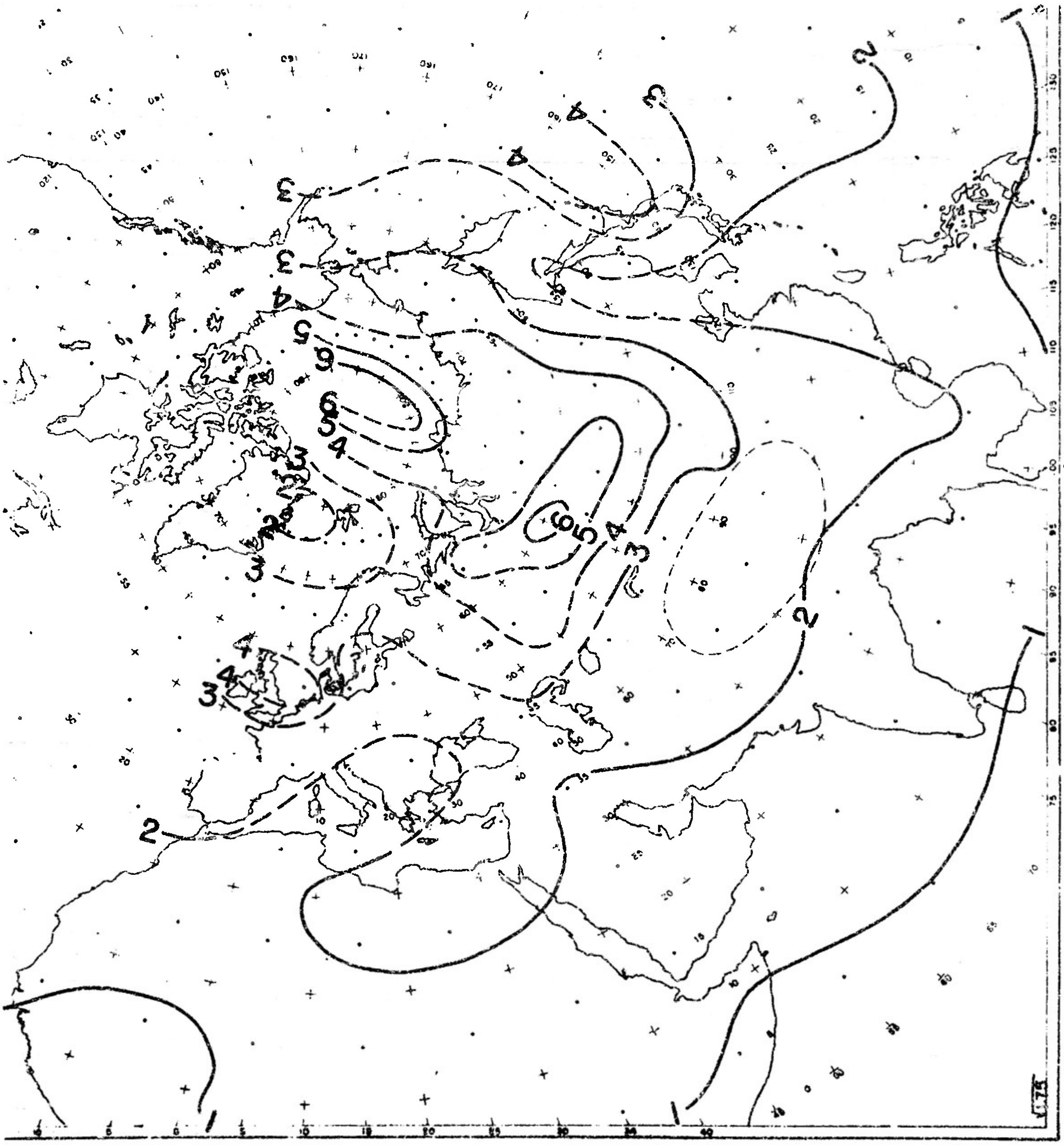
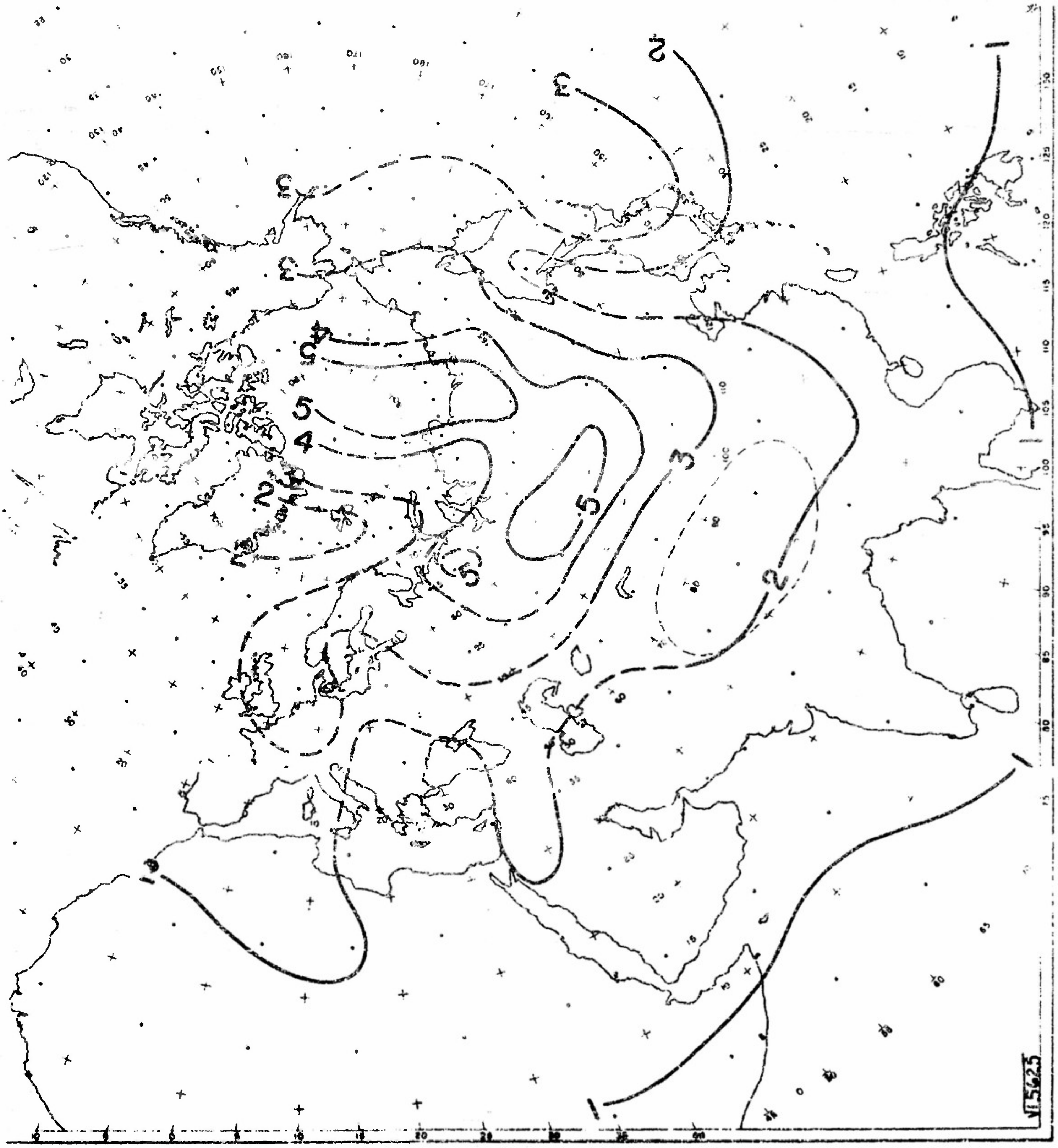


Figure (16). Range of Actual Heights at 500 mb (Zp = 18, 280 feet) in April



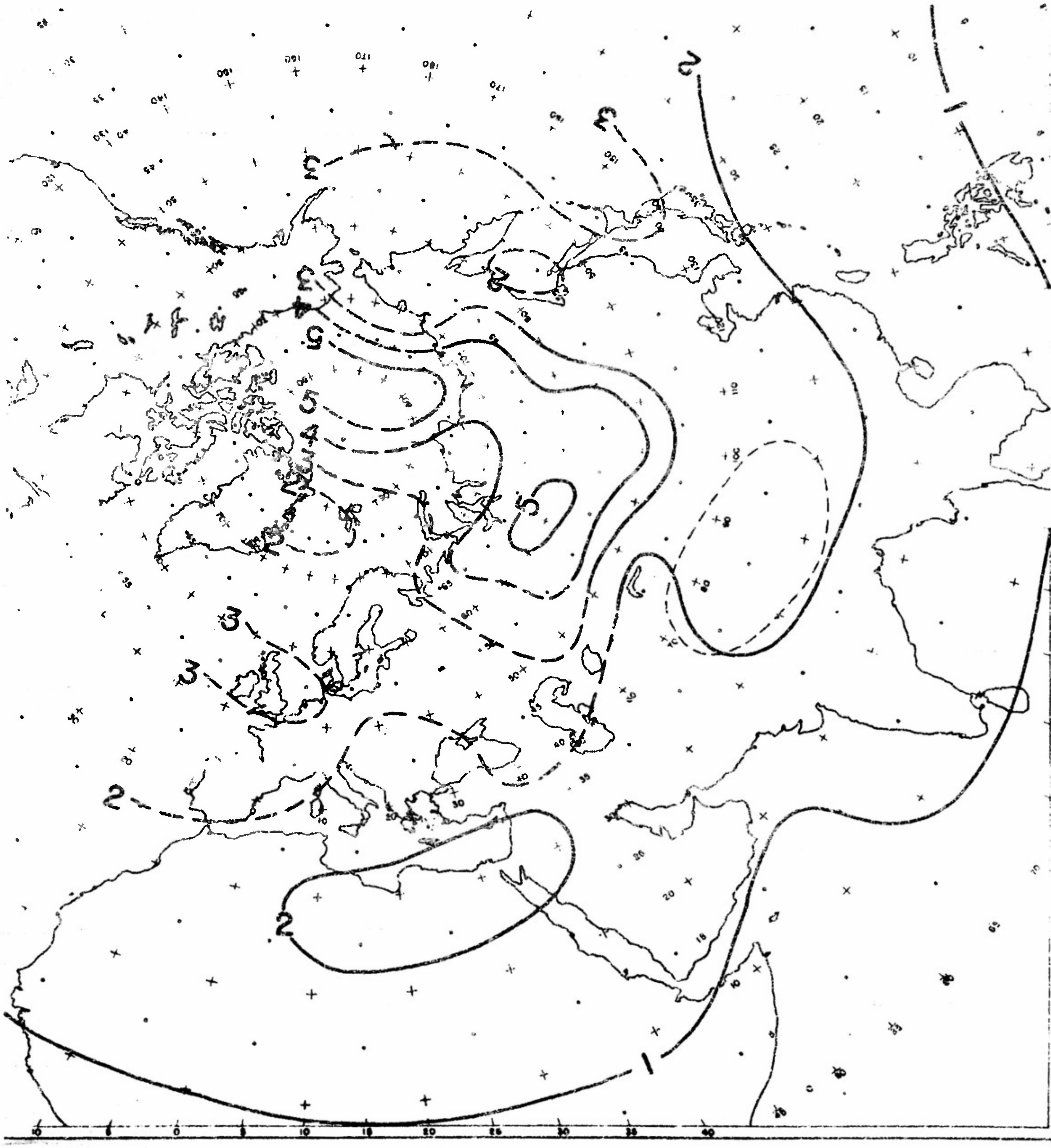
Isopleths of forecast error in hundreds of feet: 68% of errors are smaller than values shown _________ Actual - - - - - - - Estimated.

Figure 17. Forecast Error at Surface in April.



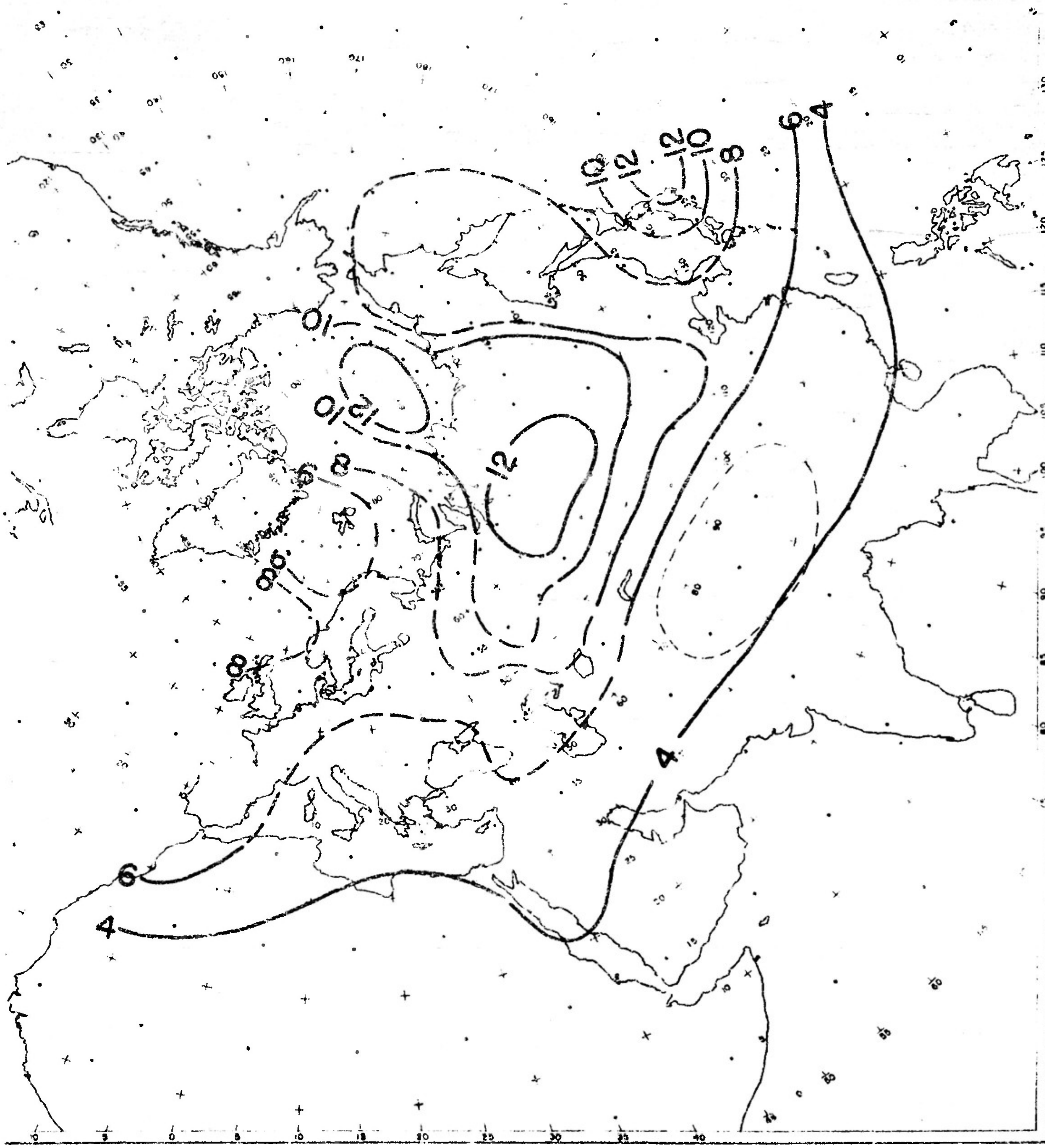
Isopleths of forecast error in hundreds of feet; 68% of errors are smaller than values shown ________ Actual - - - - - - - Estimated.

Figure 18. Forecast Error at 5000 Feet in April.



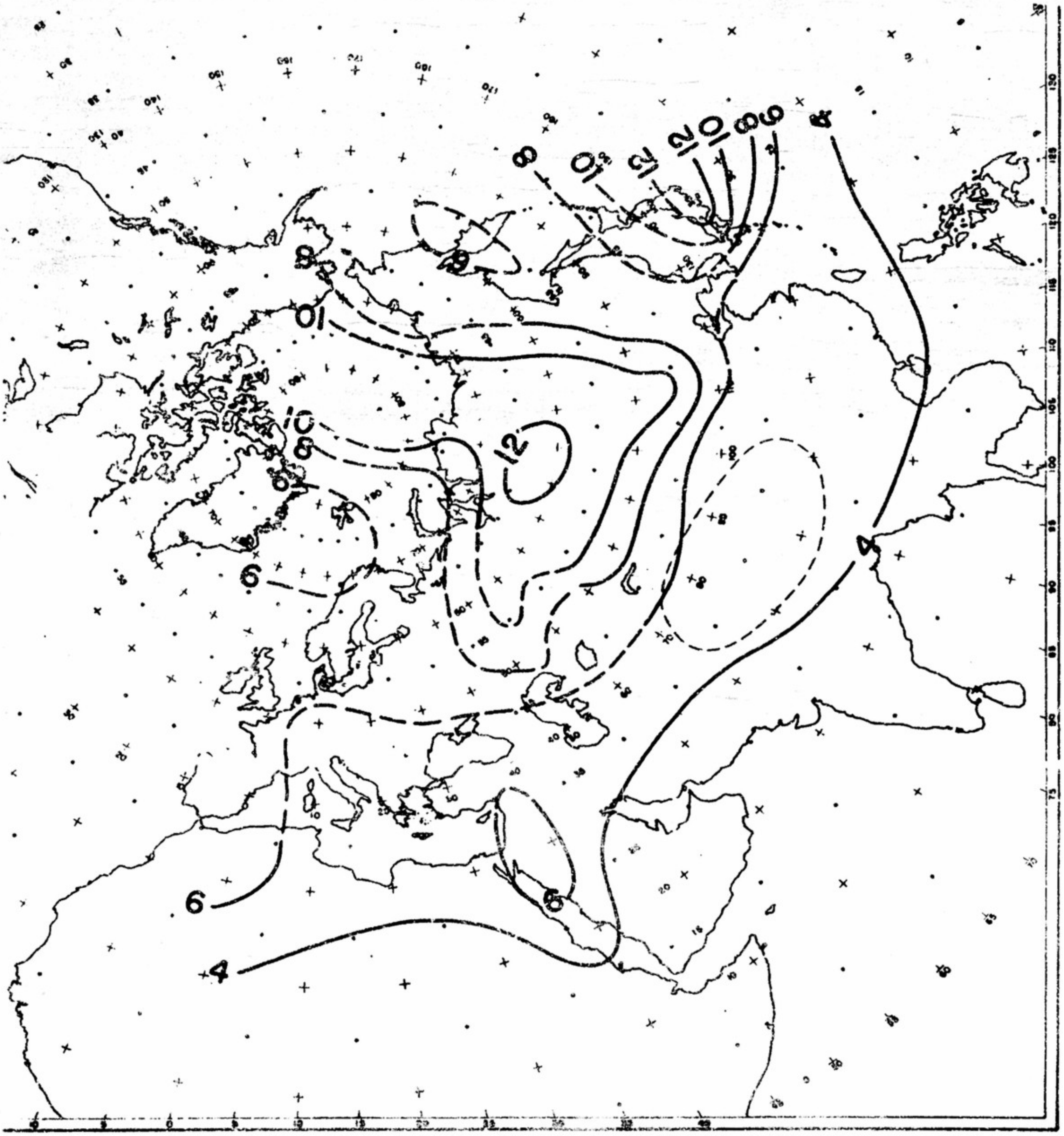
Isopleths of forecast error in hundreds of feet: 68% of errors are smaller than values shown _______ Actual - - - - - - - Estimated.

Figure 19. Forecast Error at 10,000 Feet in April.



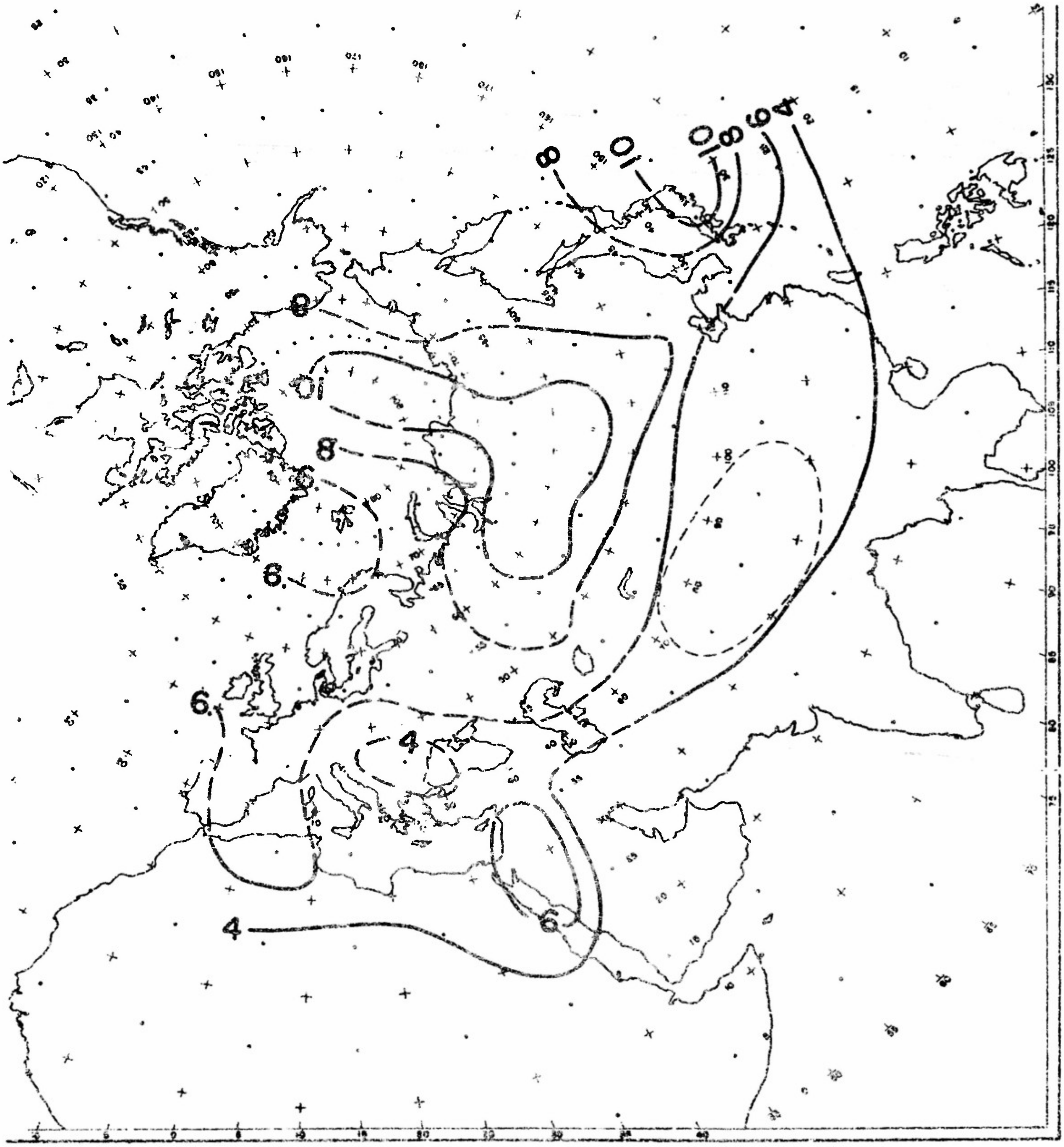
Isopleths of forecast error in hundreds of feet: 99% of errors are smaller than values shown ________ Actual - - - - - - - Estimated.

Figure 20. Forecast Error at Surface in April.



Isopleths of forecast error in hundreds of feet; 99% of errors are smaller than values shown ________ Actual - - - - - - - Estimated.

Figure 21. Forecast Error at 5000 Feet in April.



Isopleths of forecast error in hundreds of feet; 99% of errors are smaller than values shown ______ Actual - - - - - - Estimated.

Figure 22. Forecast Error at 10,000 Feet in April.

IV. ESTIMATE OF ACCURACY OF WIND FORECASTS

A wind forecast, required for operational purposes, may be given in several forms, the most likely of which is a mean wind through a considerable layer of the atmosphere. The accuracy of this forecast may be expressed in terms of the deviation in angle and speed from the wind, a) at flight level, b) a mean level (probably near 500 mb) or c) an integrated or weighted wind through the layer.

An estimate of the average and maximum errors in mean wind forecasts for the layer 5000 feet to 40,000 feet under conditions of no meteorological data was made for the Eurasian continental area. For this estimate, the wind at 500 mb (approximately 18,280 feet) was considered as the mean wind for the layer.

Two data conditions were considered. The first assumed there was no wind data available, and the second presupposed that the wind at the top of the layer could be measured and was available within 24 hours prior to the time of the forecast. It was assumed that the forecasts would be made utilizing competent meteorological personnel who had available information from the remainder of the hemisphere sufficient to carry out the analysis and forecasting routine recommended in Volume II, Chapter VII of this report.

The error is a function of the wind velocity, and is a percentage of the maximum observed winds. Since winds are greatest in February and least in August, the maximum and minimum errors occur seasonally in the same sense.

The continental area was divided into three sectors, shown in Figure (23). Forecasts are less difficult, and therefore more reliable for areas within one day's extrapolation east and west from the boundaries of the silent area. Eastward extrapolation into Sector I is most helpful in reducing speed errors. Westward extrapolation into Sector III is aided by the permanent trough in the upper flow at longitude 120° E caused by the Himalayan barrier.

Table (I) summarizes the estimates of wind forecast errors in terms of direction and speed for August and February for each of the three sectors of Figure (23) under conditions of no data, and assuming 40,000 foot winds are available.

If this forecast problem is of sufficient importance, a study of these errors based on the forecasting procedures currently under study, and climatology will both improve the estimates and reduce the errors. A suggested approach would be to:

(1) Develop mean wind patterns for several levels and times using climatic data.

(2) For each level and month develop the frequency distribution of the deviations from the normal values.

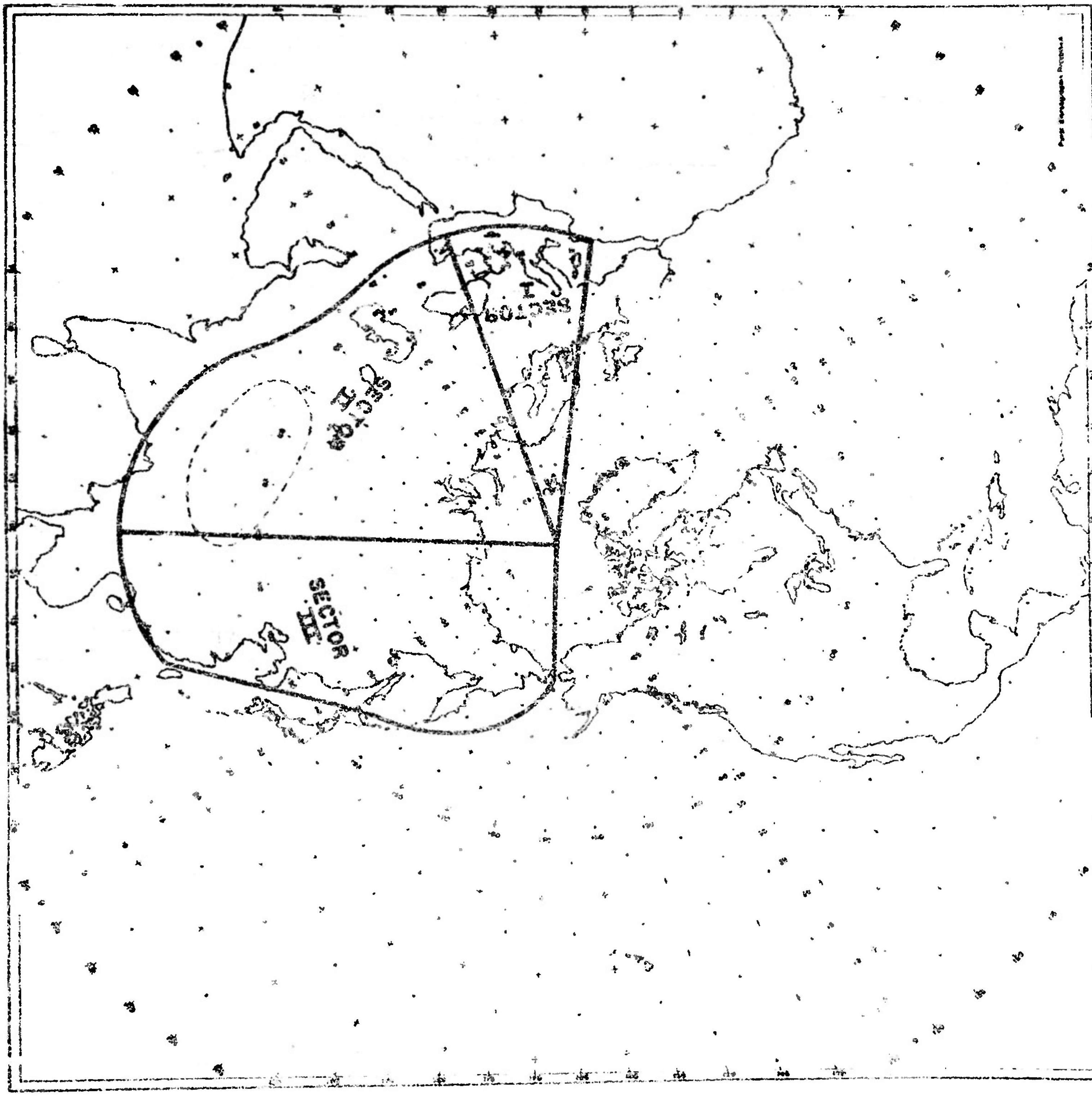


Figure 23. Sectors for Wind Forecasts

TABLE I

ESTIMATES OF MAXIMUM AND AVERAGE (MOST PROBABLE) ERRORS IN FORECASTS

SECTOR	Maximum Direction Error	Maximum Speed Error	Average Direction Error	Average Speed Error	Maximum Direction Error	Maximum Speed Error	Average Direction Error	Average Speed Error
	NO DATA							
I	50°	50 kts	30°	20 kts	50°	80 kts	30°	35 kts
II	60°	80 kts	40°	30 kts	60°	150 kts	40°	50 kts
III	40°	60 kts	20°	20 kts	40°	115 kts	20°	40 kts
	WINDS AT 40,000 AVAILABLE							
I	40°	25 kts	20°	15 kts	40°	40 kts	20°	30 kts
II	50°	40 kts	30°	25 kts	50°	75 kts	30°	45 kts
III	30°	30 kts	15°	15 kts	30°	60 kts	15°	35 kts

(3) With a knowledge of these normals and the deviations fr
them, develop techniques for predicting wind profiles b
means of pattern extension, time extrapolation, and th
large scale features being investigated under the press
height prediction project.

In the course of such an investigation, a set of charts at th
stream level (300 mb) as well as lower levels would be constructe
a hemispheric scale. Much of the other required information woul
obtained from data processed for the pressure-height problem. A
climatic background of wind normals, their deviations and variabili
would be produced and a prediction technique developed.